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# Proceedings of the

# Fourth Biennial Southern Silvicultural Research Conference

## Atlanta, Georgia
## November 4-6, 1986



**sil·vics** \'sil-viks\ *n pl but sing in constr* [NL *silva*] : the study of the life history, characteristics, and ecology of forest trees esp. in stands

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Three abstracts and 93 papers are presented in 13 categories: Pine Regeneration, Prescribed Fire, Hardwood Regeneration, Pine-Hardwood Regeneration, Seedling Production, Soil-Site-Stand Relationships, Silviculture-Economic Relationships, Interactions and Influences, Site Preparation, Management of Established Stands, Growth and Yield, Pest Management, and Vegetative Management. In addition, three poster presentations are summarized, and five papers from the general session on World Forestry Trends Affecting Southern Silviculture are included.

# Proceedings of the
# Fourth Biennial Southern Silvicultural Research Conference

Compiled by
Douglas R. Phillips

Atlanta, Georgia
November 4-6, 1986

Sponsored by

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# PREFACE

The Fourth Biennial Southern Silvicultural Research Conference was held in Atlanta, Georgia, on November 4-6, 1986. This volume contains 104 presentations from the $2^{1}/_{2}$-day conference. The meeting opened with a general session on World Forestry Trends, followed by four concurrent sessions covering 13 areas of research and a poster session. The general session was conducted for only the second time, and the poster session was presented for the first time; both were well received. In addition, a new session on pine-hardwood mixtures was added to the agenda. Also for the first time, abstracts of the papers were printed and distributed at the meeting. At this fourth conference, the Society of American Foresters was added as a new sponsor.

Initiated in 1980 and held in November on succeeding even-numbered years, the Southern Silvicultural Research Conference provides a forum for scientists actively engaged in silvicultural research to report study results, to present new concepts and techniques, to discuss topics of mutual interest, to coordinate cooperative efforts, and to remain current on developments in the field. Nonresearchers find the conferences and the proceedings to be valuable sources of information on current and developing trends in southern silviculture.

The Fourth Biennial Conference was sponsored by the Southeastern and Southern Forest Experiment Stations of the USDA Forest Service, the Southern Region of the National Association of Professional Forestry Schools and Colleges, the Southern Industrial Forestry Research Council, and the Silvicultural Working Group of the Society of American Foresters.

The Steering Committee, made up of individuals from universities, industry, and the Forest Service, are gratefully acknowledged for the time and effort they gave to assure the success of the meeting. Following are the members of the 1986 committee:

Jim Bell and John W. Henley, Conference Co-chairpersons, Southern Forest Experiment Station, New Orleans, LA

Gordon D. Lewis, Conference Co-chairperson, Southeastern Forest Experiment Station, Asheville, NC

Douglas R. Phillips, Program Chairperson, Southeastern Forest Experiment Station, Clemson, SC

M. Boyd Edwards, Southeastern Forest Experiment Station, Dry Branch, GA

Constance A. Harrington, Southern Forest Experiment Station, Monticello, AR

David L. Graney and Edwin R. Lawson, Southern Forest Experiment Station, Fayetteville, AR

David H. Van Lear, Clemson University, Clemson, SC

Eric Jokela, University of Florida, Gainesville, FL

D. M. Crutchfield, Westvaco Corporation, Summerville, SC

Howard Hanna and Tim McIlwain, Container Corporation of America, Fernandina Beach, FL

Special thanks are extended to the contributors who prepared and presented research papers and to the 16 moderators who presided over topic sessions and maintained a very strict time schedule. Thanks also to others who submitted abstracts for consideration by the Program Committee and to those who attended the conference and participated in the discussions.

Papers published in this proceedings are as they were submitted by the authors--in camera-ready form. Authors are responsible for the content and accuracy of their papers. Printing and production were supervised by the editorial staff of the Southeastern Forest Experiment Station, USDA Forest Service, Asheville, North Carolina.

DOUGLAS R. PHILLIPS
Program Chairman

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# World Forestry Trends Affecting Southern Silviculture

Moderator:

Robert C. Kellison
North Carolina State University

# Technology Development for Increased Use of Hardwoods[1]

Peter J. Ince[2]

Abstract.--New developments in technology are altering the historical dominance of softwood over hardwood as a preferred raw material for many kinds of products. Developments span the whole range of forest products, from traditional products such as lumber, wood panels, and paper, to energy uses and biotechnology. In the lumber area, new drying technology overcomes the problem of excessive warp in low density hardwoods and permits their use for framing lumber. In addition, new technologies are being developed to make lumber substitutes from wood strands or wafers, that enable use of higher density hardwoods in applications where softwood lumber is used exclusively today. In the structural panel area, waferboard and oriented strandboard panels are replacing conventional softwood plywood in a substantial share of the market. These new panel products can be made entirely from hardwoods. In pulp and paper, a general trend toward greater use of hardwood fiber is evident as the proportion of industry capacity dedicated to production of printing and writing grades increases. Also, improvements in pressing, drying, and refining technologies are allowing high quality linerboard to be made with much higher proportions of hardwood. A growing use of wood for energy, in residential heating and industrial uses, favors hardwoods because of their higher density. Finally, through biotechnology, hardwoods will probably play a more significant role than softwoods. Consequently, silvicultural knowledge about lower valued timber species, such as hardwoods, needs to be developed for the future.

Keywords: Technology, hardwoods, silviculture.

## INTRODUCTION

This paper addresses ongoing technology developments for increased use of hardwoods. A wide range of technological and economic developments are described that are reducing the advantage of softwood over hardwood as a preferred wood raw material.

These developments reflect a principle of human behavior which I call the "leveling principle." The principle says that when less expensive resources are available, people develop new technologies to use less expensive resources. Thus, people seek to level the advantages of more expensive resources in order to improve economic efficiency. This kind of very rational human behavior presents complexity for silvicultural researchers, because it means that as you focus your objectives on timber species that you think will have the highest value in the future, others will be trying consciously and vigorously to develop new technologies to utilize the less expensive timber species.

## OBJECTIVES OF SILVICULTURAL RESEARCH?

Let me begin by asking a very general question: What are the objectives of silvicultural research in the South? No doubt you've wrestled with this question before. If we had time to ask everyone about silvicultural research objectives, we would probably find a variety of ideas. However, among the most practical objectives we would find a common goal something like the following: to expand knowledge needed to improve abundance and quality of timber resources which society will demand in the future.

The problem is that we can't say for certain what kind of timber resources society will demand 30 or 40 years from now, so it's difficult to say what kind of silvicultural knowledge needs to be developed. It would be easy to set silvicultural research objectives if we could believe, for example, that growth in the southern pine plywood industry, observed in the past 20 years, will continue into the next century. But, believe me, that would ignore some important developments taking place in structural panel technology.

Evidence suggests that future forest product technology is not necessarily going to be anything like the past. Industry is developing technologies to level the advantages of higher value timber resources and to enable the use of lower value timber resources. For example, technology is being applied that allows the use

[1]This paper was presented in the General Session of the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, GA, Nov. 4-6, 1986.

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of low density hardwoods or softwood pulpwood in place of softwood veneer logs in manufacturing structural panels. Developments are occurring also in lumber, structural panels, pulp and paper, energy, and biotechnology. We will look at specific examples in each of these areas. I hope that as I discuss these examples, you will recognize their significance in terms of silvicultural research objectives in the South. Let's look first at the framing lumber area.

Technology to Produce Hardwood Framing Lumber

Softwood dominates the market for framing lumber in the United States. Last year, we consumed nine times as much softwood lumber as hardwood, and in structural framing we depend entirely on softwood.

Historically, industry has avoided the use of low density hardwoods for framing lumber largely because of the problem of excessive warp. Years ago, grading rules were established which limited allowable warp to small fractions of an inch in all but the lowest grade of framing lumber. Because of the way that framing lumber is used in modern construction, each piece needs to be dimensionally precise and stable. Unfortunately, hardwood lumber would typically come out of a conventional sawmill and drying process with excessive warp. Because of this dimensional stability problem, production of hardwood framing lumber was not economical.

However, in our Eastern forests, net growth and volume of hardwood exceed that of softwood. Forests in the South contain increasingly abundant quantities of inexpensive low density hardwoods such as yellow-poplar, sweetgum, blackgum, and soft maple. These hardwood species have strength values between southern pines and spruce-pine-fir, and can be nailed easily or joined with truss plates.

Researchers have now developed a sawmilling innovation that eliminates the problem of excessive warp in hardwood framing lumber. The innovation is called Saw-Dry-Rip, or SDR. With SDR technology, the mill saws a log into full width flitches. The flitches are dried, and then sawn (or "ripped") into warp free framing lumber. The key innovation is that framing lumber is cut from the wood after drying, instead of before, as in conventional sawmilling. This simple innovation eliminates the problem of warp (Maeglin and Boone 1983).

Recently, a recommended grading stamp was developed for yellow-poplar framing lumber, and building codes will now accept yellow-poplar lumber (Allison and Deal 1983). The new hardwood lumber is less splintery than softwood, is lighter and easier to handle than southern pine, and tests show that yellow-poplar lumber has higher truss plate holding capacity than southern pine. In demonstration projects, the hardwood lumber appears to be a very attractive structural material.

With SDR technology, you can envision a sawmill able to use either low density hardwoods or softwoods. In the future, there will be less differentiation between softwoods and low density hardwoods for framing lumber.

The point I am making is not a forecast but simply a recognition of present capability. The technology is now available which levels the advantage of softwoods over low density hardwoods in framing lumber. So long as softwoods remain economical and abundant, as they are now, you can expect that softwoods will continue to dominate the framing lumber market. But, if softwood becomes too expensive relative to low density hardwoods, you can expect to see a switch to hardwoods. If you are a silvicultural researcher developing knowledge based on an assumption that softwood sawtimber will have a tremendous market advantage over hardwood in the decades ahead, I would suggest that you might go back over your assumptions. You might also consider silvicultural research objectives that will foster improved management of the low density hardwood resource in the South.

Technology to Produce Hardwood Structural Panels

The structural panel market is also an area in which softwood traditionally dominated, but where things are now changing.

Until recently, softwood plywood thoroughly dominated the structural panel market. Softwood plywood itself was a major technological development of the early part of this century, and the softwood plywood industry grew tremendously in the South in the 1960's and 1970's. Today, more than half of U.S. softwood plywood is produced in the South. There is no doubt that the tremendous growth of the southern pine plywood industry contributed enormously to an enthusiasm for pine silviculture in the South.

However, if you look closely at construction sites around the country these days, you will see that a growing share of the structural panels are a new class of products, known in the market as waferboard and OSB (oriented strandboard). In the 1970's at the Forest Products Laboratory we developed computer models of manufacturing processes for these kinds of products. We were quite enthusiastic about how economical the process was relative to conventional plywood technology. Part of the reason for our enthusiasm was the fact that waferboard and OSB technology offered the ability to use lower quality timber, such as pulpwood instead of veneer logs, and hardwood instead of softwood. As many of you know, this kind of technology exists now, not just in the form of a computer model, but in the form of a growing and rapidly expanding industry.

The new waferboard and OSB structural panel products provide excellent structural performance and are accepted by building codes as a substitute for softwood plywood in most types of construction. Although performance is comparable

to softwood plywood, the new waferboard and OSB products are cheaper to produce. As a result, we have seen the industry installing new waferboard and OSB mills in significant numbers in recent years, while we see almost no capacity expansion in softwood plywood.

Growth of the U.S. waferboard and OSB industry has been exponential. From only one plant with a capacity of 100 million square feet as late as 1979, the industry has grown to a capacity of nearly 4 billion square feet, by late 1986, and the growth is continuing (Anderson and Hutton 1986). Today, waferboard and OSB capacity equals nearly 20 percent of U.S. softwood plywood production, and 12 percent of total structural panel capacity. Industry is locating many of its new waferboard and OSB mills throughout the South.

Many new waferboard and OSB mills in the South will be using southern pine pulpwood because of the economic abundance of the resource and good board quality that is obtained with southern pine. However, there is a demonstrated ability to use many species of hardwoods in the waferboard and OSB products. Most mills in the North use hardwood species exclusively, and some mills in the South are using hardwood species as well.

Besides being economical to produce, waferboard and OSB products offer much more latitude for product innovation. Structural components can be made in an infinite variety of molded forms and shapes which are not attainable with conventional lumber or plywood technology. Most significantly, unlike structural wood products of the past that were made entirely out of softwoods, the structural products of the future can be made out of small diameter hardwoods, using technology similar to waferboard and OSB technology. Even the hardwoods such as oak may be useful, as in thick roof decking samples that have been made in the laboratory from southern red oak. Simple innovations, such as using longer strands or detaining better strand alignment, will also enable the industry to take full advantage of the inherent strength in dense hardwood species. The market is already seeing the introduction of high strength parallel strand lumber, made by gluing together long strands of wood. In the future, lumber substitutes and complete structural components may be made from hardwood wafers and strands, using technology similar to waferboard and OSB.

Once again, I am not really making a forecast, but simply pointing out the current status of technological development. If your silvicultural research objectives are based on an assumption that there will be growing demands for softwood veneer logs, I would suggest that you go back over your assumptions. Structural panel products can be made economically from small diameter, low quality, hardwood species, as well as from small diameter softwoods.

## Technology to Utilize Hardwood Fiber in Pulp and Paper

The U.S. pulp and paper industry is another important market area where softwoods have dominated, but where new technology is leveling advantages of softwoods over hardwoods. Pulpwood consumption increased over the last 20 years by about 75 percent, to a present level of 90 million cords per year. Over 65 percent of that pulpwood comes from Southern forests. As most of you know, the largest share of that pulpwood is southern pine, and pine pulpwood generally has a higher value than hardwood pulpwood.

The technical advantages of pine versus hardwood can be explained in terms of morphological differences between softwood and hardwood fibrous material. Softwood fibers are comparatively long and flexible. Softwood fibers naturally provide good strength characteristics in products like kraft linerboard. By comparison, hardwood fibers are generally smaller, shorter, and less flexible. Consequently, hardwood does not provide good strength performance with conventional technology, although hardwood can provide a smoother sheet with better opacity, which is useful in printing and writing grades (Amidon 1981).

One major technological trend is toward increased production of those grades of pulp and paper products which utilize more hardwood fiber. Production of hardwood-based pulps, which include bleached and semibleached hardwood kraft and semichemical pulps, has increased more rapidly than production of all other grades of pulp. Consequently, in the South, we have seen hardwood pulpwood go from around 15 percent to nearly 30 percent of pulpwood consumption in the past 30 years (Ince 1986). This trend is continuing, particularly with recent conversions of a number of mills from packaging grades to printing and writing grades. Even in packaging grades, the need for good surface printability has led a number of mills to increase their demand for hardwood furnish. These gradual changes, favoring increased use of hardwood pulpwood, are expected to continue in the future. However, a much more dramatic kind of technological development is underway, and that involves development of new technology that will produce high strength paper and paperboard products from hardwood fiber.

Manufacturing pulp and paper involves a series of process steps. Wood chips are converted into pulp in digesters and refiners. The pulp goes in a slurry to the paper machine, where pulp is formed into a fibrous mat, pressed, and subsequently dried. Conventional papermaking is largely a felting process, in which sheet strength depends on random interlocking and conformability of fibers. Therefore, long flexible softwood fibers have always provided better strength than short stiff hardwood fibers.

However, in recent years, new pressing equipment, including high pressure and wide nip

presses, have been installed in many linerboard mills. With the new equipment, much better quality is obtained with higher proportions of hardwood and recycled fiber (Wicks 1983). Furthermore, researchers have developed an even more advanced technology, known as press drying. Unlike conventional papermaking, press drying involves simultaneous application of heat and pressure in the press section of the paper machine, resulting in good conformability and bonding among hardwood fibers. With press drying, a very good kraft linerboard can be made from 100 percent hardwood, such as southern red oak (Horn and Setterholm 1983). The press drying technology is not yet available commercially, but it appears economical, and it illustrates a potential technological capability to utilize much higher proportions of hardwood fiber in pulp and paper products. In addition to improved pressing technology, improvements are being made in technology for refining pulp fibers, for putting strength enhancing chemical additives in paper and paperboard, and for producing higher quality hardwood pulp with mechanical pulping processes.

As a result of these technological developments, there has been a significant leveling of the former advantage of softwood fiber in pulp and paper technology. The industry has only begun to adopt these technological improvements, and change will be gradual, but we can no longer point to a future in which softwood fiber will absolutely dominate because of its fiber characteristics. In fact, it is possible to conceive of a future in which hardwood fibers may be preferred over softwood fibers in pulp and paper technology.

## The Increasing Importance of Wood for Energy

Another development favoring the future use of hardwood is the increased importance of wood for energy in our economy. As a result of energy price shocks in the 1970's, we have seen a substantial shift toward increased use of wood for residential heating, particularly in rural America. Even though the South has a warmer climate than northern regions, fuelwood use is significant because of a large rural population. Across the United States, we are consuming about 49 million cords of fuelwood for residential heating per year (Energy Information Administration 1986). Of the 49 million cord total, about 16 million cords are consumed in the South. In addition, several million cords of fuelwood are being used directly for industrial energy. Provided that petroleum and gas prices stabilize in the years ahead, I expect to see a leveling off of the increase in fuelwood demand. Still, I would expect that fuelwood will continue to be an important use for wood in the future.

The important thing about the increased use of wood for energy is that hardwood species are preferred by households, the major roundwood users. A nice seasoned piece of red oak burns better and longer than softwood in fireplaces and woodstoves. In all regions of the country, fuelwood producers have appeared. These commercial operations derive their income in the fuelwood market. Other wood product companies that have traditionally derived income in different markets have also branched out into the fuelwood market. They advertise and sell their fuelwood in both rural and urban areas, amd are utilizing primarily hardwood.

I'm not suggesting that silvicultural researchers should give total attention to the growth of hardwoods for fuelwood. There is certainly a tremendous abundance of low quality hardwoods in the South that will adequately serve needs for fuelwood in the future. However, in your process of establishing silvicultural research objectives, you should consider not only such things as precommercial thinnings and pulpwood harvests in softwood stands, but also such things as fuelwood thinnings or fuelwood harvests in hardwood stands. Perhaps if fuelwood demand is put into the equation, you will find that hardwood silviculture looks a little more attractive.

## Hardwood Use Associated With Biotechnology

A final area of technological development that I'd like to talk about is biotechnology. Most of you are aware of the importance that biotechnology has assumed in many areas of research. Biotechnology is no less important in the area of wood utilization research. At the Forest Products Laboratory, we recently organized biotechnology research into an institute, which we call the Institute for Microbial and Biochemical Technology. The scope of research in this area is expanding. The focus continues to be on basic research, with possible applications in biopulping, and promising applications in bleaching, modifying pulp properties, removing chemicals, and treating effluent (Kirk et. al. 1983).

Most of the wood biotechnology research is directed at utilization of the abundant and inexpensive hardwood resource. For one thing, the molecular structure of hardwood and softwood lignins are different. Hardwood lignin is more readily and rapidly biodegraded than softwood lignin. Another reason why biotechnology is focusing on hardwoods is a matter of economics. Hardwoods are relatively cheap and abundant, whereas softwoods are already in high demand. In addition, hardwood biotechnology is receiving greater attention because the chemistry of hardwoods is approximately the same as that of agricultural crop residues, which are also receiving much research attention. Xylans, from which xylose sugar is derived, are abundant in hardwood hemicellulose and agricultural residues, but not in softwoods. Utilization of glucose sugars from ordinary cellulose is already feasible, but utilization of xylose is one aim of current research.

It is hard to say where this research will lead 30 or 40 years from now, but it is apparent that the biotechnology of the future may just as

likely utilize hardwoods as softwoods. In fact, due to differences in lignin chemistry and comparative economics, bio-utilization of hardwoods may be more near at hand than bio-utilization of softwoods.

## CONCLUSION

Change in technology is a gradual process, so we won't see a wholesale switch to hardwoods from softwoods overnight, or even in a matter of 5 or 10 years. Change in forest management techniques is also a slow process. However, to be effective in the future, changes in the philosophy of silvicultural research should be made today. Technological change is relentless and it can have profound impacts on resource utilization. Look at how improvements in basic energy technology over the past 15 years have dramatically altered the world market for oil. There used to be an oil shortage, now there's an oil glut. Of course the leveling principle in human behavior is limited by laws of thermodynamics and laws of nature. But, when we look at the forests of the Eastern United States, when we look at the differences between hardwoods and softwoods, and when we look at current human endeavors aimed at reducing the advantage of expensive softwoods over cheap and abundant hardwoods, we do see that this leveling principle is at work. In summary, there is a message here for silvicultural researchers: We should be critical of time-worn guidelines regarding such things as optimal species, stand conversion, site preparation, and other factors related to species distribution. When we do research that enables foresters of the future to grow timber resources that we think will have the highest value 30 or 40 years from now, others in society will be attempting consciously and vigorously to change technology in order to utilize other lower valued timber species. If we find that our research, particularly our basic research, is focusing narrowly on only a few species that are currently in high demand, we should consider how we can expand our research to focus on other species as well. It may be feasible for example to inexpensively replicate our experiments across a wider array of species, so that we develop more silvicultural knowledge about species that may be in greater demand in the future. We should recognize that, where feasible, silvicultural knowledge about lower valued timber species, such as hardwoods, needs to be developed for the future.

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# INTERNATIONAL TRADE AND SOUTHERN FORESTS[1/]

James E. Granskog[2/]

Abstract.--The value of southern wood exports has dropped by more than a third since 1980, after rising sharply during the 1970's. Major factors in the recent decline were a worldwide recession and a strong U.S. dollar, which made southern wood products more expensive overseas. However, trends for individual products have varied; exports of softwood plywood and hardwood lumber have grown while other product shipments have fallen. Currently, a weakening U.S. dollar appears to be turning the overall trend for southern wood exports upward again.

International trade is becoming increasingly important to our nation's economy. In 1985, imports and exports accounted for 21 percent of our country's gross national product--almost double the percentage from 20 years earlier. Perhaps more enlightening is that 70 percent of all products manufactured in this country now face international competition. In other words, markets for most U.S. products no longer are determined solely by domestic forces.

Timber markets also have been vulnerable to foreign influences. A strong rise in the value of the U.S. dollar in the first half of the 1980's--which made U.S. products more expensive and foreign goods cheaper--has increased the flow of forest products from abroad. Domestic markets for lumber, pulp, and paper products have been impacted by rising imports of softwood lumber from Canada, and new inflows of eucalyptus pulp from Brazil and coated paper from Scandinavia.

While recent events have focused attention on the import side of international trade, there has been nonetheless a growing interest in exporting forest products as well. This interest has been stimulated by a combination of factors, including:

- unstable domestic markets for wood products over the past decade,
- expanding foreign competition in certain product lines,
- forecasts of slow growth in domestic wood markets and faster growth overseas, and
- a national concern over a widening trade deficit and the need to increase the sale of products abroad.

As a result, potential markets overseas are being viewed as a vital ingredient for future growth.

To support the growing interest in exporting forest products, the Southern Forest Experiment Station has been conducting research aimed toward investigating the potential for southern wood products in overseas markets. In this paper, recent trends for the principal wood products exported from the South are examined, and the outlook for southern wood products in foreign markets is discussed.

Although exports represent only a small fraction of total production for most southern forest products, they are important from a value standpoint. For the most part, export demand for wood products is for high-quality material. Exports can enhance timber values, thereby encouraging more complete utilization while providing incentives for more intensive silvicultural practices.

## SOUTHERN WOOD EXPORTS

Southern exports of wood products have been declining since 1980, following a dramatic rise during the 1970's (table 1). The total value of southern exports rose from near the $50 million level in the early 1970's to almost $500 million in 1980, but it has dropped by more than a third since then.

Several factors have influenced this rise and fall, but currency fluctuations have been a key item. The strong upturn during the 1970's was stimulated by a weakening U.S. dollar. In effect, prices for southern wood products--in terms of foreign currencies--were reduced. Other contributing factors to the upturn were: a rising demand overseas, other global sources becoming constrained by resource depletion or government restriction, and a growing recognition among domestic producers of the importance of diversifying markets. Trial shipments of wood chips to Scandinavia, in particular, seemed to trigger a greater awareness of the market potential abroad.

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[1/] Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2/] Principal Economist, Southern Forest Experiment Station, USDA Forest Service, New Orleans, LA 70113.

Since 1980, however, changing economic and monetary conditions have turned the direction for southern wood exports downward. First, a worldwide economic slowdown lowered total demand. Then the continuing rise in the value of the dollar through early 1985 made southern wood products more expensive and less competitive in foreign markets. But a recent weakening of the U.S. dollar since March 1985 has stopped the decline and appears to be turning the trend upward again.

Table 1.—Value of southern wood exports by product group.

| Product | 1970 | 1975 | 1980 | 1985 |
|---|---|---|---|---|
| | | Million $ | | |
| Roundwood | 15.3 | 26.9 | 93.4 | 52.2 |
| Lumber | 26.6 | 37.0 | 206.0 | 160.0 |
| Panels | 3.3 | 18.2 | 59.6 | 61.6 |
| Other | 13.1 | 16.4 | 140.0 | 52.1 |
| Total | 58.3 | 98.5 | 499.0 | 325.9 |

Among the major commodity groups, lumber is the largest export, on the average accounting for about 45 percent of the total value of shipments. However, only panel products have increased since 1980. The size of the miscellaneous group--primarily millwork and prefabricated wood buildings--was inflated in 1980 by a huge, one-time shipment of prefabricated housing to Syria. Roundwood shipments include logs, poles, and chips.

Markets

Europe, the Caribbean, and the Far East are the largest regional markets for southern wood products (fig. 1). Most important within Europe are the nations in the European Economic Community (EEC). The Caribbean market includes the West Indies and Central America. Japan, Taiwan, and South Korea are the primary destinations in the Far East. The remaining markets are made up mostly of the oil-exporting countries in the Middle East, Africa, and South America.

The material shipped to each of these markets is different. In general, EEC nations have been major buyers of the principal hardwood exports (logs, lumber, and veneer) as well as selected southern pine products (plywood and rough-cut clear lumber). Wood chips for Scandinavia and rough southern pine lumber have been the primary products shipped to European countries outside the EEC. The Caribbean is largely a market for softwood products, while the Far East is a southern hardwood market. Oil-producing countries in the Near East region import poles and prefabricated wood buildings.

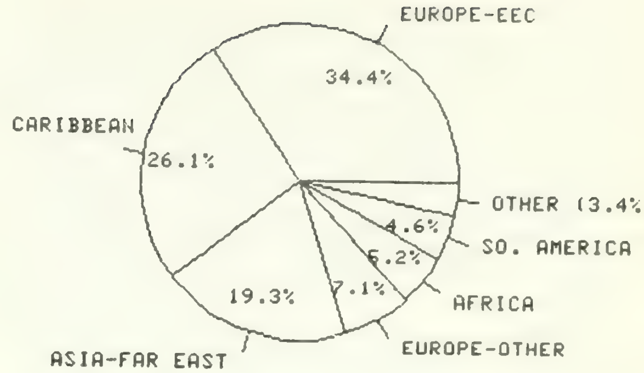


Figure 1.--Export markets for southern wood products.

Products

Trends since 1980 for individual products have varied according to the markets served and the specific items demanded in those markets (table 2).

Table 2.--Southern wood product exports, 1980 and 1985.

| Product | 1980 | 1985 |
|---|---|---|
| Roundwood: | | |
| Softwood logs (mill. bd. ft.) | 7 | 5 |
| Hardwood logs (mill. bd. ft.) | 44 | 37 |
| Poles (thousand) | 142 | 87 |
| Chips: (thousand tons, dry) | 424 | 67 |
| Lumber: (mill. bd. ft.) | | |
| Softwood | 274 | 191 |
| Hardwood | 67 | 86 |
| Panels: (mill. sq. ft.) | | |
| Veneer, softwood | 46 | 9 |
| Veneer, hardwood | 336 | 206 |
| Plywood, softwood | 62 | 179 |
| Plywood, hardwood | 12 | 14 |
| Particleboard | 11 | 2 |
| Miscellaneous: (mill. dollars) | | |
| Cooperage | 9 | 3 |
| Prefabricated buildings | 101 | 24 |
| Other | 30 | 25 |

Roundwood

Southern log exports are mostly hardwood. Softwood log shipments have been relatively small, fluctuating between 5 to 10 million board feet annually. Southern pine logs going to the

Caribbean area generally make up most of the softwood shipments. Most hardwood log exports have been oak veneer log shipments to the EEC nations in Western Europe. Shipments fell from a peak of 44 million board feet in 1980 to around the 20 million-board foot level from 1982 through 1984, due to the combined effects of the recession in Europe, the strong dollar, and EEC import restrictions relating to oak wilt disease. However, hardwood log exports increased in 1985 in response to a rising demand for hardwoods in the Far East.

In spite of the strong dollar and recession overseas, southern pole exports were relatively strong through 1983, but then declined. The Caribbean and the oil-exporting countries in the Near and Middle East are the primary markets, and falling oil prices have been a factor influencing the recent decline.

Exports of roundwood pulpwood from the South are insignificant, but wood chips are a noticeable item. Following a series of trial shipments in the mid-1970's, which culminated in long-term supply agreements with Sweden, southern chip exports grew to a high of almost 740,000 oven-dry tons in 1981, when the market was expanded by shipments to Finland and Norway. But shipments have dropped steadily since then. Expiration of the Swedish contracts, a Norwegian bankruptcy, currency devaluations in Sweden and Finland, and the strong dollar all combined to dampen demand. Finland was the only buyer in 1983 and 1984, but it banned further imports after discovering the shipments contained the pinewood nematode, a microscopic worm that causes pine wilt disease in Scotch pine. Last year there were shipments to Sweden, but Sweden and Norway also joined the ban on chip imports in February of 1986 because of the nematode problem. Future shipments are uncertain at the moment. A trial shipment of treated chips to Sweden took place in August, and winter shipments have been mentioned as a possibility. But the Scandinavians also plan to test treated wood chips from Canada, and they have signed a 1-1/2-year agreement for radiata pine chips from Chile.

Lumber

Softwood lumber is the South's most important solid wood export. Softwood lumber shipments are mainly southern pine, although about 30 million board feet of nonsouthern species are exported annually out of southern ports. Most of the nonsouthern softwood goes to the Caribbean countries, largely due to the proximity of the region to southern ports and the ability of lumber dealers at those locations to fill small orders of various species for specific uses.

Southern pine lumber goes to two major overseas markets -- the Caribbean and Western Europe. Exports to the Caribbean have increased since 1980 but exports to Europe decreased by a larger amount, resulting in an overall decline for softwood lumber. The Dominican Republic, Jamaica, and Trinidad are the biggest buyers in the Caribbean; West Germany, Italy, and Spain lead in Western Europe.

Southern pine lumber exported to Europe is primarily clear material, which is used for joinery, paneling, and furniture parts. Most is shipped rough for remanufacture to metric sizes and because of an EEC tariff on dressed lumber. On the other hand, most of the pine shipped to the Caribbean is for structural purposes, and a majority is dressed. Also, it is estimated that about a quarter of the material going to the Caribbean is treated lumber.

Unlike softwood lumber exports, southern hardwood sales abroad have increased since 1980. The principal reason is that a new market has developed in the Far East as shipments to Europe have declined. Recently, Taiwan and South Korea have begun to manufacture furniture from American hardwoods, as log export restrictions in Southeast Asia have forced a restructuring of their wood-using industries and raw material sources. Also, hardwood lumber sales to Japan have become notable. In 1985, the Far East region surpassed the European market, and it now takes half the South's hardwood lumber exports.

Wood-based Panels

Panel products form the only group for which the value of all shipments has increased since 1980. Most southern panel exports consist of softwood plywood and hardwood veneer.

Softwood plywood export sales skyrocketed to 262 million square feet in 1981--up from a previous high of 62 million square feet the prior year. While there has been a slight decline since then, the level of export shipments has remained strong relative to the 1970's. Acceptance of U.S. plywood grades in European building codes for use in structural applications has boosted southern pine shipments. Ninety percent of the softwood plywood export sales in 1985 went to the EEC.

Before softwood plywood exports took off in 1981, hardwood veneer was the primary wood panel export. Impacted first by the recession in Europe, which accounted for 80 percent of 1980 sales, and then the strong dollar, shipments slid to the 200 million-square-foot level by 1982. Sales have remained flat since then, as rising sales to the Far East have offset a further decline in exports to Europe.

Relative to softwood plywood and hardwood veneer, other panel exports are small. For a number of reasons, this might be expected. First, most softwood veneer produced in the South is integrated with plywood manufacturing, which leaves little independent veneer production available for sale or trade. Second, the U.S. is a major importer of hardwood plywood, so exports naturally are small. And third, in the case of particleboard, Europe has a well-developed industry to serve its needs. Overall, most of the minor panel exports are concentrated in the Caribbean area.

## Miscellaneous Products

In addition to the primary products, the South exports a variety of manufactured items or products of secondary manufacturing. Since there is no common measure of volume, only the value of shipments is shown in table 2. Of the numerous products covered in this category of exports, cooperage and prefabricated wood buildings are of particular interest.

Cooperage is one wood export that has steadily declined over a long period. In the late 1960's, cooperage accounted for 20 percent of the total value of southern wood exports, ranking second only to southern pine lumber. By 1985, it amounted to less than 1 percent of the total. When inflation is factored in, the decline in real terms has been about 95 percent.

Prefabricated wood buildings have replaced cooperage as the largest miscellaneous product export. Shipments of modular construction camps to the oil exporting countries became a noticeable item following the first surge in oil prices in 1973. In 1980, as mentioned earlier, there was also a huge shipment for government sponsored housing in Syria.

More recently, however, the construction camp market has dried up and a new market for rustic, recreation-oriented type structures has developed. For the South, shipments have been primarily for resort developments in the Caribbean islands, but nationwide there have also been shipments to Japan and other Pacific destinations. In any case, the demand is for panelized structures, pre-cut kits, and log homes, all of which can be shipped in containers. This substantially reduces handling and transportation costs, which can be excessive for modular units and mobile homes.

# OUTLOOK

As noted at the outset, the dollar's steady rise during the early 1980's made southern wood products more expensive and less competitive in foreign markets. However, the more recent dollar decline is producing signs of a turnaround. Although exports of southern pine lumber and plywood were down slightly overall in 1985 compared to 1984, shipments in the third and fourth quarters were above the previous year. And for the first half of 1986, southern pine lumber exports were up 14 percent and southern pine plywood jumped 59 percent.

Exchange rate developments will continue to affect the prospects for southern wood exports, but long-term impacts are uncertain. It's largely through exchange rates that the relative competitive position of different countries is established. Indeed, the head of GATT--the General Agreement on Tariffs and Trade--recently stated that tariffs, on the average, are no longer important obstacles to world trade. What counts more, in his opinion, are exchange rates for national currencies. What lies ahead is difficult to say, but more and more there are proposals calling for limits or ranges to be established to improve the current floating exchange system and prevent the wide fluctuations that have occurred over the last decade.

Whatever the outcome, an important point concerning exchange rates is how changes affect the markets that are significant for southern wood products. For example, based on recent currency shifts and considering exchange rate effects alone, the South should see increasing exports to Europe, stagnation or decline in the Caribbean because of currency devaluations, and some additional growth in the Far East due to the rising Japanese yen. These effects may be enhanced or moderated by other factors, however.

Exchange rates aside, the outlook for southern wood exports appears favorable--provided world economic conditions continue to improve, free trade policies prevail over protectionist forces, and the forest products industry maintains a commitment to expand export markets.

In western Europe, we should see opportunities to increase exports of clear southern pine lumber, southern pine plywood, high-quality hardwood lumber, and hardwood veneer. Two products that have been important previously--hardwood logs and wood chips--may not recover due to restrictions relating to oak wilt disease and the pinewood nematode. Also, a European quota for softwood plywood is an obstacle, since a 10-percent tariff is levied on amounts that exceed the quota. But southern pine's share of the total U.S. plywood exports continues to rise; it reached 53 percent in 1985 after averaging only 5 percent during the 1970's.

In the Caribbean, future shipments of southern softwood products will depend largely on the rate of economic progress in the area, the actions of competing softwood suppliers, and whether exporting programs are designed to meet the unique characteristics of the market. Although per capita incomes are relatively low in most countries, rapidly expanding populations are generating housing needs that support continuing imports due to the lack of domestic softwood resources. Political instability in Central America has disrupted the flow of lumber from that area, but Honduras--our largest competitor in the region--is expanding sawmilling capacity. Chile also has been a recent supplier of Radiata pine lumber in the region. Thus maintaining or expanding southern shipments will require aggressive and innovative marketing efforts.

The developing market for hardwoods in the Far East has become important, and may become even more so. This is somewhat of a mixed blessing, however, since U.S. manufacturers must compete with furniture imports that are coming back into our country.

An encouraging development for future southern wood exports has been the involvement of industry trade associations and government agencies in the promotion of wood products in foreign markets. Associations such as the Southern Forest Products

Association (SFPA), and the American Plywood Association (APA), in cooperation with the National Forest Products Association and the Foreign Agricultural Service, have developed programs that will support increased sales to countries that offer opportunities for export expansion. For example, both the SFPA and APA have conducted educational seminars in Caribbean countries where the use of softwood products could be expanded. In addition, SFPA placed a European representative in London in 1985, and more recently added a Caribbean representative in the Dominican Republic.

Success in developing foreign markets, however, may be determined in large part by the extent of the commitment of southern producers to exporting. In the past, interest in exporting has declined as domestic markets improved, leaving U.S. producers with a reputation as unreliable suppliers. But progress is being made in changing this perception. Several recent articles in foreign trade journals have noted a growing commitment by U.S. producers to exporting, as well as a favorable view concerning our reliability compared to other world sources of wood products.

Summing up our recent export performance and the outlook: the South has not done as badly as the initial overall value trends may have suggested, since several product exports have remained strong; however, it may not do as well in the future as the popular reports about the decline in the dollar might lead us to believe, as most exchange indexes do not reflect all of the currencies in markets important for southern wood products. Nevertheless, there are opportunities that should be pursued--both to more fully utilize the highest value potential from our forest and to help reduce the nation's trade deficit. One thing is certain: the international marketplace can no longer be ignored if southern forests and forest industries intend to survive and grow in today's integrated world economy.

# THE LATIN AMERICAN FORESTRY EXPERIENCE[1]

J. Zweede[2]

Abstract.--Among Latin American countries, Brazil has the greatest potential for becoming a major force in world wood and forest products markets. The Amazon Basin contains 570 million ha. of forest land. Only 5% of this area's forest has been permanently cleared. Relatively little progress has been made in managing of existing forests in the Amazon Basin, but in central and south Brazil much land has been planted with Eucalyptus and pine. Yields in successful Eucalyptus plantations have been very high, and plantations are supplying about half of the nation's wood needs for forest industries, steel manufacturing, and fuelwood. Between 1970 and 1980, the value of wood products exports from Brazil grew by 660%, and continued growth is anticipated. With major investments in forestry, Brazil could become a leading world supplier of wood and wood products.

In traveling to the meeting in Atlanta, I flew from the city of Belem, at the mouth of the Amazon Basin, to the city of Manaus, halfway up the Amazon. This flight took 2-1/2 hours by jet over nothing but forest broken only by the occasional cleared patch of land caused by shifting agriculture. One could continue and fly another 3 hours on to the city of Quitos, Peru, over the same continuous forest.

While flying I was reading an article by World Watch stating that 40% of the forest would be cleared by the year 2000. That would mean clearing on the order of 16 million ha./year and destroying 3 billion tons of wood. On the other hand, in the first 391 years of the Amazon's settlement only 5% was permanently cleared (NASA 1986). Why so little clearing? I believe the answer is that it is difficult and expensive to clear this land.

This forest, instead of being the legendary lung of the world, produces its own acid rain and gases, aiding the greenhouse effect (INPA/NASA 1986). The article about this largest and most controversial forest accepts no middle-of-the-road thinking on utilization and sustained productivity. One has to choose between destroying this forest and leaving it forever wild.

Returning to the topic of the paper--it's rather difficult to cover South American forestry in this short time. Certainly many others are more qualified to cover the various topics. However, a unique opportunity and experience was afforded to me in that within a 12-year period, the project I was associated with:

1. cleared land
2. established plantations
3. harvested the tree crops
4. produced high grade pulp
5. replanted and coppiced a second generation
6. and, not least of all, learned from lots of mistakes.

In other words, short-rotation, high-yield plantation forestry is practiced in South America and is a resource potential we will have not only to accept but also understand as professionals.

As we discuss South America in more detail, keep in mind the prerequisites for development of the forest resources:

1. land
2. right amount and distribution of people
3. infrastructure
4. capital goods industry
5. capital for investment and operating.

We tend to take these items for granted. However, they are limiting factors for many developing countries.

## FORESTRY IN SOUTH AMERICA WITH EMPHASIS ON BRAZIL

In order to discuss forestry, we should first situate ourselves.

### I. Latin America

Latin America is composed of 21 countries on 2 billion ha. of land as compared to the remainder of North America with 2 countries and also roughly 2 billion ha. of land. Latin America as a whole is a net importer of forest products (1980 net imports = $924 million).

Honduras is the only net exporter in Central America (1980 - $4 million). The restraining factors in Central America are high population, limited land availability, other land use priorities (fruiticulture and horticulture on better soils), and shifting agriculture. However, some very good forestry work has been accomplished such as the work by CATIE and seed work on Caribbean pine and other tropical pines. A high priority has been placed on production of fuelwood for individual consumption.

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[1]Paper presented at Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2]Consultant, Seneca, South Carolina.

## II. South America

South America is composed of 13 countries on 1.7 billion ha. of land. Forest occupies 56% or 957 million ha. of this land. The Amazon Basin alone has 570 million ha. of forest land. In order to relate this--the forested land of the world today is estimated at 4 billion ha.

South America is a net exporter of forest products (net exports 1980 = \$340 million). However, this figure is misleading because the only two net exporters are Chile and Brazil (Net exports = \$1.21 billion). The three other large forest product producers, Argentina, Columbia, and Venezuela, are all net importers (\$400, \$100, and \$222 million, respectively).

All have very active plantation forestry projects, including innovative ones like the Savannah Pine plantations in Venezuela and Columbia. The strongest growth has been in Chile (oldest forest products industry and plantation forestry) and Brazil. Some countries like Surinam accumulated a great wealth of R&D in forest resources during colonial times but no application. In general, population pressure, forest distribution, and other land uses have kept the other countries from developing their forest resources.

## III. Brazil, Past, Present, and Future

### General

Brazil has more than 50% of the total land, forest land, and forest products production of South America and is now considered a world class exporter. In order to relate, let's look at some comparative statistics.

| Brazil | | United States |
|---|---|---|
| 850 mil. ha. | Total land | 937 mil. ha. |
| 570 mil. ha. | Total forest | 292 mil. ha. |
| 300 mil. ha. | Brazilian Amazon | |
| 135 mil. | Population | 236 mil. |
| 200 mil. | (est. yr. 2000) | |
| 142 mil./$M^3$ | 1970 roundwood prod. | 334 mil./$M^3$ |
| 245 mil./$M^3$ | 1980 roundwood prod. | 390 mil./$M^3$ |
| \$5 bil. | 1980 trade deficit | |
| \$5 bil. | 1983 trade surplus | |
| \$100 bil. | Foreign debt | |

In some respects, I compare Brazil in its state of development to the United States in the early 1950's during its resource expansion period.

### FOREST AND FOREST PRODUCTS INDUSTRY

Development and growth in the forest products sector of Brazil can be shown by changes in the following statistics:

| 1970-1980 | Units | Change |
|---|---|---|
| Sawn wood | $M^3$ | 85% |
| Panel products | $M^3$ | 210% |
| Wood pulp | T | 312% |
| Paper | T | 176% |
| Wood product imports | \$ | 388% |
| Wood product exports | \$ | 660% |
| Net trade | \$ | 910% |
| 1980-1985 | | |
| Roundwood | $M^3$ | 25% |

Of Brazil's total forest land, 570 million ha., 300 million ha. are unexploited reserves containing 45 billion $M^3$ of wood in heterogeneous tropical forest.

Although Brazil still imports \$250 million of forest products, of which 50% is from the U.S., it has changed its status during the past decade from net importer to net exporter. The value of forest products produced annually is \$1.2 billion, of which exports account for \$916 million.

The pulp and paper industry, for example, grew at a rate of 10%/year for the last 15 years. The value of exports in this sector was \$180 million in 1979 and \$514 million in 1983. Today, the 160 small to medium pulpmills produce 3,600,000 T./yr. of wood pulp.

The energy forest often spoken of today is very real in Brazil. In 1980, 20 million TOE (tons of oil equivalent) in wood were consumed for energy, or 24% of the country's energy need. Brazil has no coal to speak of, especially coking coal for the steel industry. Charcoal has always been used for this purpose. Most people don't realize that over 50% of all wood produced by Brazil ends up as charcoal for the steel industry, 30 million $M^3$/yr., and another 30 million $M^3$/yr. as direct fuel.

The natural forest still plays a big role (50% of wood produced) in the forest product industry, and most of this is in the Amazon Basin area. Selective logging provides wood for more than 1200 small to medium sized forest products industries.

Not commonly known is the fact that once-cleared land reverting to secondary forest is supplying much of the wood for the export industry. The more homogeneous pioneer species supply a better resource than the climax forest.

### FORESTRY DEVELOPMENT

Plantation forestry was stimulated in 1916 when the Railroad Company of the State of Sao Paulo sent a botanist to Australia to collect *Eucalyptus* seed. Many *Eucalyptus* species were tested and planted along the railways to provide fuel. As mentioned previously, the steel industry followed quickly, establishing plantations for charcoal production.

In the steel producing areas, the natural forest has been cut. Thus plantation forestry for charcoal and direct energy consumption developed rapidly in central Brazil.

In 1966 two events occurred. The Brazilian forest Service (IBDF) was established and the "tax incentive investment law for reforestation" was instituted. Very quickly, a few million hectares

were planted in Eucalyptus species and the first large-scale pine plantations (mostly loblolly and slash) were established.

Due to entrepreneurial manipulation of funds, lack of forestry knowledge, and the short time frame, a lot of these plantations were unsuccessful and a lot of money was wasted. However, some U.S. companies with plantation forestry experience and some very responsible Brazilian companies established a very good resource base. Most of the development occurred in the central South region. The pulp and paper industry had its strongest growth due to the effect of this investment incentive.

Other laws were passed to stimulate and protect forest resources. Example are:

1. plant 4 trees for every $M^3$ used by any industry
2. 50% of any land ownership has to stay in natural forest.

These two laws have had very little impact in reality. We won't discuss their failure.

The Amazon region was and is the last to develop any sort of plantation forestry or rational management of the natural forest. Some futile attempts have been made with the natural forest. There are two significant examples of plantation forestry. The Amcel project of planting tropical pines on savannah land has done quite well and today has developed 50,000 ha. The Jari project (controversial as it may be) has in a short time (18 years) proven and disproven many theories of plantation establishment in the tropics.

Although economically the Jari project is debatable, biologically and forest resource-wise, it made a great impact on forest development in the tropics. It demonstrates the potential for forestry applications in other tropical environments.

FORESTRY PRESENT AND FUTURE

Much development has taken place in the last 15 years. Many exotics were planted. More Eucalyptus species have been planted in Brazil than in any other country. Both U.S. southern pines and tropical pines are being planted. Of all southern and related pines planted in the world, 10% are being planted in Brazil. Other exotic species, such as Gmelina arborea and Acacia spp. have been commercially planted.

To date, 6.6 million ha. are in plantation management, of which 70% is Eucalyptus, 25% pine, and 5% other. In 1985, the plantation establishment schedule was 1 million ha., with 55% Eucalyptus, 35% pine, and 10% other. Of the plantations established, 65% were with tax incentive money of the total sum of $180 million.

The actual harvest in 1986, not counting the natural forest, is 80 million $M^3$ and 800,000 ha. Rotation ages vary from 3-7 year for Eucalyptus to 8-16 years for pine. Average MAI per year can produce 15 to 30 $M^3$ over the rotation. To state that 25 $M^3$/ha./yr. can be a fact would be no overstatement.

With genetic improvement and crossing, some Eucalyptus plantations are producing 75 $M^3$/ha./yr. with a tendency to reach 100 $M^3$/ha./yr. As with most plantations in Brazil, these are fertilized. However, with these yields many silvicultural activities will be sound investments.

Brazil's targeted roundwood harvest from plantations in the year 2000 is 267 million $M^3$ yr. The year 2000 target also includes a total of 14 million ha. in tree plantations, replanting 2 million ha. per year, and an employment of 1.1 million people in this sector. If only 50% of this near-impossible program is achieved, it will provide a resource base that will affect world trade, even though at last 50% will be consumed by the steel industry and by energy requirements.

Brazil, in fact, has the necessary land, climate, and technological expertise to become a leading world supplier of wood and wood products. However, an annual investment of over $1 billion for forestry alone would be required.

CONCLUSION

There is no doubt that several countries in South America, due to their land base, climate and labor, could develop a strong forest industry. So far, only Brazil and Chile have developed this resource as an export potential. However, if the desire to develop this resource is matched with capability, some areas in South America could become a strong factor in world wood fiber markets.

The two most limiting factors are capital availability and the existing socio-economic philosophy. The philosophy of many developing countries is that forestry and forest industries are too primitive and have no place in a developed country except as a predatory activity.

Certainly, plantation resource development is a great achievement. However, the vast majority of forested hectares in Latin America are still in climax forest and the greatest problem is still how to manage and develop these forests rationally. In the Amazon Basin, this need is especially urgent. Of the 570 million ha., only 5% has been cleared so far, but pressure does exist for land utilization. The race to clear the forest for conversion to cattle pasture of the 1970's has luckily slowed down. Ths conversion and land use was an ecological disaster. Tree crops may be the answer, but how and what are the great questions that need an urgent answer.

# CURRENT AND FUTURE WOOD SUPPLY TRENDS IN AUSTRALIA, NEW ZEALAND AND CHILE[1]

Dr. W. R. J. Sutton[2]

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Abstract.--Australia, New Zealand and Chile are not significant wood producers. Their current combined harvest is only 12.3 million cunits - i.e. only 1/17th the combined annual harvest of the USA and Canada. A comprehensive review of their forest potential (mostly plantations) shows that none of the three countries will increase production to the levels which have recently been published. In all three countries, scope for production increases is limited before the mid 1990's. Australia will remain a net importer well into the next century. New Zealand and Chile between them could be producing an additional 7 to 10 million cunits per year by the year 2000. Given the low levels of these increases, and given the perceived market opportunities in Asia, the "threat" to North America from the forests of the South Pacific Rim is much less than many now believe.

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## DISCLAIMER

Where possible, factual material used in this paper is either referenced or the source identified. Decisions on which data source to use must introduce a degree of subjectivity. Interpretation of the data also involves elements of subjectivity. All such decisions and interpretations are my own. They are not necessarily those of the company for whom I work.

## INTRODUCTION

This paper summarises for Australia, New Zealand and Chile:

(a) The present supply situation;
(b) The structure of the plantation resource; and
(c) Projections of future yield.

The paper is an updated, but shorter version of a paper given in July 1985 in Vancouver to the Pacific Rim Markets for Forest Products (1985-2000) (Sutton 1985).

Australia is the largest of the three countries. Its area is only fractionally less than the USA (excluding Alaska). Chile is much smaller - 1/10th the area of the USA. New Zealand is smaller still. Its total area only equals the State of Colorado or about 1/30th that of the 48 contiguous States.

## PRESENT SUPPLY SITUATION

The most recent wood harvest statistics are summarised in Table 1. The total harvest statistics for the USA and Canada are also given for comparison. By North American standards, the three South Pacific countries are not significant producers. USA production is around 30 times that of Australia, just over 40 times that of Chile, and nearly 50 times that of New Zealand. On present levels, the combined harvest of Canada and the USA is 17 times that of the combined harvest of Australia, New Zealand and Chile.

Ninety-three percent of New Zealand's wood supply comes from plantations of introduced trees (mostly radiata pine). In Chile 90% of the harvest is radiata pine. Australia's plantation production (again, mostly radiata pine) is as yet unimportant, supplying only 30% of Australia's total requirements - the balance comes from indigenous forests (mostly eucalyptus). New Zealand and Chile are net exporters of wood.

New Zealand exports just on 1.4 million cunits (logs, sawn timber, chips, pulp and newsprint. Chile exports about the same wood volume in much the same products. Australia is a net importer.

Current industrial and trade levels are given in Table 2. Although these production and export levels are significant to the relatively small economies of New Zealand and Chile, neither country can be regarded as a significant producer or exporter at world level. Combined production totals for the USA and Canada for the major forest products is 50 times, or more, the levels achieved by either New Zealand or Chile. Australian imports, except in mechanical pulp, are in excess, and sometimes well in excess, of New Zealand's exports.

## FUTURE WOOD SUPPLIES

There is widespread belief, almost fear, that the plantations of the three countries will soon mature and that significant, ever increasing volumes of wood will be placed on the world market. Many see these volumes as a real threat to the traditional forest products producers and exporters, especially in North America.

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[1]Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2]Tasman Forestry Limited, Private Bag, Rotorua, New Zealand

Table 1.--Current annual wood harvest

| Country | Information Source | For Year | Wood Harvest (million cunits/year) Indigenous Forests | Plantation Saw-logs[1] | Plantation Pulp/Other | Plantation Total | Total Supply |
|---|---|---|---|---|---|---|---|
| Australia | BAE (1985) | 1984 | 3.6 | 1.0 | 0.7 | 1.7 | 5.3 |
| N.Z. | [2] | 1985 | 0.2 | 1.8 | 1.3 | 3.1 | 3.3 |
| Chile | INFOR (1986)[3] | 1985 | 0.4 | 1.8 | 1.5 | 3.3 | 3.7 |
| USA | FAO (1986) | 1984 | | | | | 154.7 |
| CANADA | | 1984 | | | | | 56.8 |

Notes and Sources:

[1] Sawlogs include peeler logs and logs for export
[2] Valentine (1986) Table 16
[3] From Table 33 of INFOR (1986) Plantation values are those for radiata pine Only. All other assumed to be indigenous.

Table 2.--Current Production and trade of forest products

| | AUSTRALIA Production | AUSTRALIA Balance of Import/Export | NEW ZEALAND Production | NEW ZEALAND Balance of Import/Export | CHILE Production | CHILE Balance of Import/Export |
|---|---|---|---|---|---|---|
| Sawntimber (million bd ft) | 1208 | (-439) | 978 | 200 | 928 | 300 |
| Logs for export (thousand cunits) | - | - | - | 127 | - | 449 |
| Wood chips for export (thousand BDU's) | - | 2170* | - | 322 | - | Neg |
| Mechanical Pulp (thousand long tons) | 229 | (-5) | 572 | 259 | 158 | Neg |
| Chemical Pulp (thousand long tons) | 430 | (-225) | 573 | 168 | 680 | 503** |
| Newsprint (thousand long tons) | 378 | (-190) | 298 | 187 | 172 | 116 |

Source: Australia 1984 BAE, 1985 (*Green tonnes value converted to b.d.u.'s by multiplying by 0.444)
New Zealand 1985 Valentine 1986
Chile 1985 INFOR 1986

(*Separate export figures for mechanical and chemical pulp are not available but almost all exports will be of chemical pulp.)

The plantation resources, age class structures, and projections of future supply for each of the three countries are reviewed below.

## CURRENT AREA OF PLANTATIONS

The most recent estimate of plantation areas is given in Table 3.

Australia has just on 2 million acres of plantation forest. Sixty-seven percent is radiata and other pine species, mostly in Queensland, make up the balance.

New Zealand has just under 2.6 million acres of plantation, 86% of which is radiata - 2.4 million acres.

Chile is now reported to have the greatest area of plantations of the three countries - approximately 3 million acres. Chile also has the greatest area of radiata pine - 2.6 million acres - 87% of the country's total plantation area.

Future wood availability from plantations depends partly on the rate of earlier planting (and restocking of felled plantations) and partly on other factors such as growth rates, commercial thinning and age at final felling.

## RATES OF PLANTATION ESTABLISHMENT

Figure 1 gives the annual planting rates for the three countries. For New Zealand, estimates begin from 1921, for Australia 1945, and Chile 1952.

New Zealand's plantings during the late 1920's and early 1930's aimed to provide increasing volumes of wood for the domestic market from the 1960's onwards. It was expected that by then supplies from the slow growing and largely non-renewable indigenous forests would be nearly exhausted. New Zealand's initial planting effort was not matched by the two other countries. However, during the 1950's and 1960's Australia created new plantations faster than the other two countries (between 12,500 and 25,000 acres per year more). New Zealand's rate of new planting was usually t lowest of the three, but there was little difference between New Zealand and Chile.

Through the 1960's the rate of new planting increased in all three countries. By the early 1970's all were planting about 75,000 acres per year. Since the mid 1970's, there have been majo differences. Over the last 10 years (1974-1983) Australia's average rate of planting was 91,000 acres per year. New Zealand's was 113,000 acres per year and Chile's an impressive 205,000 acres per year.

New planting is not the only contributing fac tor. New plantings are supplemented by regenerat clearfelling. This is particularly important in New Zealand because clearfelling of the 1925-35 plantings began in the 1950's and has continued ever since.

A more realistic measure of the plantation resources, and their potential, is the age class distribution of the plantations.

## AGE CLASS DISTRIBUTION OF THE PLANTATION RESOURCE

The published age class distributions of plar tations as of the end of 1983 are given in Figure All plantations are included for Australia. For New Zealand, figures for all plantations, and for radiata only are included. For Chile, only the radiata plantations are available.

New Zealand has a significant area of trees older than 36 years. More than half of that is in species other than radiata pine (mostly Douglas fir) Nearly all the old radiata pine crop will be felled before 1990 to sustain supplies until significant areas of new planting become availabl for harvest.

Table 3.--Total Area of Plantations - 1984/5
(million acres)

| Country | Source | Total Area | Radiata Pine Only | |
|---|---|---|---|---|
| | | | Total Area | As % of Total |
| Australia | 1 | 2.07 | 1.38 | 67 |
| New Zealand | 2 | 2.71 | 2.37 | 88 |
| Chile | 3 | 2.94 | 2.57 | 87 |

Sources:

1. BAE (1985a) Table 3.
2. Valentine (1986) Table 9.
3. INFOR (1986) Table 14.

Figure 1 ANNUAL NEW PLANTINGS

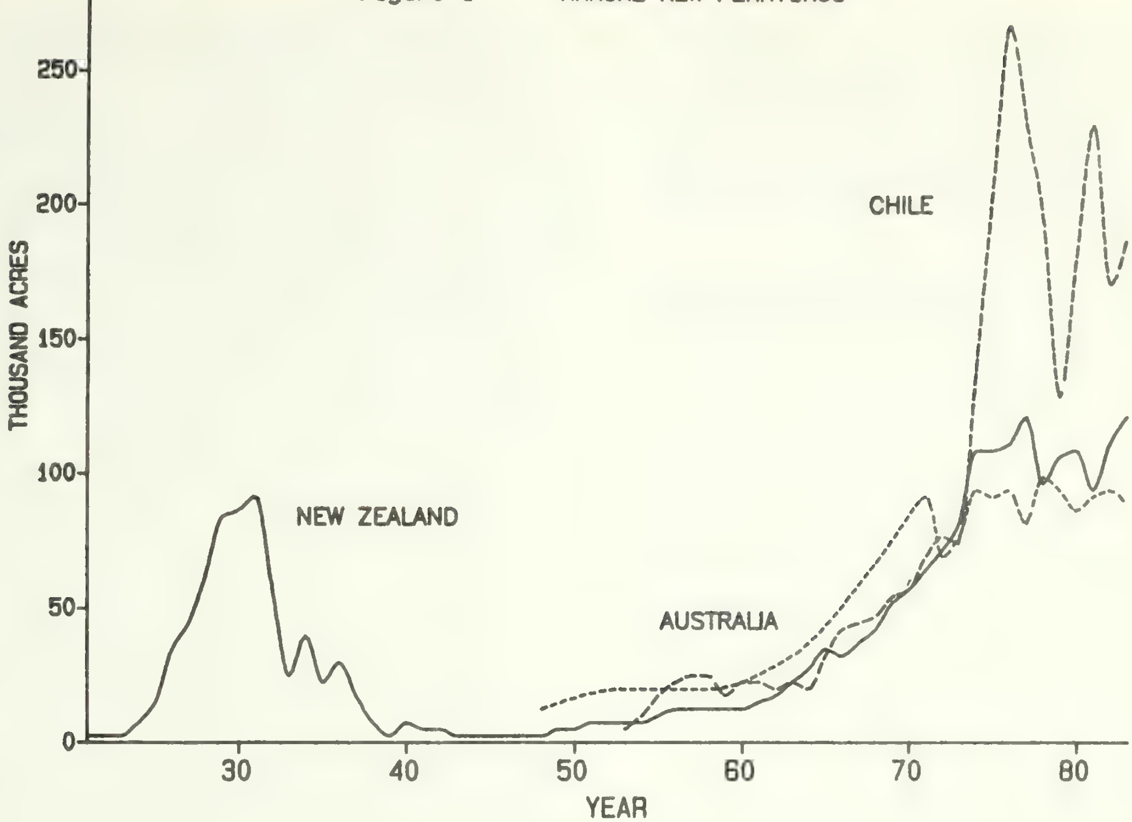
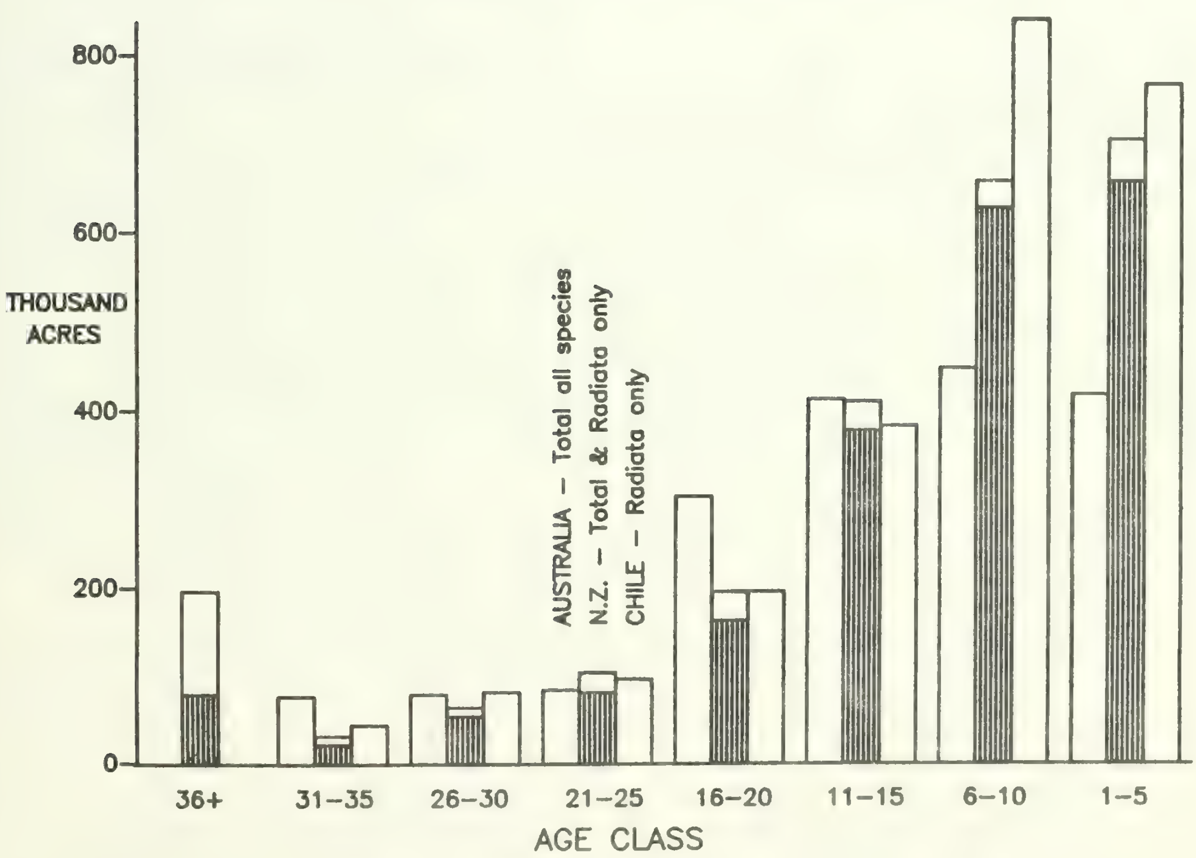



Figure 2 PLANTATION AGE-CLASS DISTRIBUTION



None of the countries has significant areas of plantations older than 20 years. So unless rotations are short (i.e. considerably shorter than 30 years), it is impossible to greatly increase plantation wood yields until the mid 1990's. There are some possibilities for yield from commercial thinnings in younger stands but, except possibly in Chile, thinnings are not expected to significantly increase yields within the next decade.

New Zealand and Chile have equal areas (195,000 acres) of 16-20 year old stands. Australia is ahead with 200,000 acres. For the 11-15 year age class, all three countries have very similar areas (380-410,000 acres).

Australia has the smallest area of stands less than 10 years, and Chile the most. Assuming, reasonably, that average growth rates are similar for both countries, the advantage Chile has over New Zealand is almost entirely in stands younger than 10 years. Chile can only have greater volumes available for felling than New Zealand, if Chile clearfells her forests earlier. Sustainment - let alone increased production - is only possible for both New Zealand and Chile if the planting rates of the last decade are maintained.

## PROJECTIONS OF FUTURE SUPPLY

In this section I attempt to provide the most realistic assessment of future yields. I report and comment on projections made by authorities in each country.

But, a note of caution. Predictions are estimates based on a series of assumptions. They may, or may not, represent what will actually happen. It is important to repeat a warning about projections given by Valentine and Wije-Wardana (1985).

"The New Zealand projections were based on a particular set of assumptions. However, as the Director-General of Forests has noted: 'No projection of forest yields at a national level can be described as accurate or precise. Any single projection simply represents a possibility chosen from a wide array of such possibilities...' (Kirkland 1984). We cannot over-emphasise that observation."

These remarks refer specifically to New Zealand but they apply equally to the other two countries.

## AUSTRALIA

Over the last five years there have been several projections of future Australian supply through to the year 2000-2010. The most recent is being prepared by the Australian Forest and Forest Products Industy Committee (FAFPIC). Their preliminary estimates, not yet published, are very similar to the 1981 projections of the Australian Forestry Council (AFC) 1981. In 1985 the Australian Bureau of Agricultural Economics (BAE) published projections of future yield for two alternative harvesting options. Again, values were very similar, especially where rotations were assumed to be 40 years. Reducing the rotation to 30 years significantly increased harvest levels (see Table 4). I believe that Australia will aim for longer rather than shorter rotations and that the 1981 projections for plantations are probably the most realistic.

Table 4.--Projections of total future wood supply (volumes in million cunits)

Australia

| Projection Source | 1985 | | | 1990 | | | 2000 | | | 2010 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NP | P | Tot | NP | P | Tot | NP | P | Tot | NP | P | Tot |
| AFC '81 | 3.8 | 2.4 | 6.2 | 3.7 | 3.1 | 6.8 | 3.5 | 4.5 | 8.0 | 3.5 | 5.5 | 9.0 |
| BAE 1 | | | | 3.7 | 3.2 | 6.9 | 3.6 | 4.0 | 7.6 | 3.3 | 6.6 | 9.9 |
| BAE 2 | | | | 3.7 | 4.5 | 8.2 | 3.6 | 6.6 | 10.2 | 3.3 | 8.3 | 11.6 |

Notes: P = Plantations (all assumed to be conifer).
NP = Wood from all other souces (mostly indigenous forest).

AFC '81 = from Tables 8 & 9 of Australian Forestry Council, AFC (1981).
BAE 1 = Option 1 of BAE (1985) - 40 yr rot., 20% pulp, $16m^3$/ha/yr.
BAE 2 = Option 2 of BAE (1985) - 30 yr rot., 30% pulp, $19.8m^3$/ha/yr.

Both BAE projections assume
- five thinnings
- a continuous new plant in a rate of 34,000 hectares per year

All BAE values interpolated from figures 2 and 3 of BAE (1985).

The most questionable aspect of the projections is the predicted supply for the indigenous eucalypt forest. All projections, including the preliminary 1986 estimates by FAFIPC suggest that the indigenous supplies will continue, with only a slight drop, well into the next century.

However, at the recent 12th All Australia Timber Congress Conference (August 1986) several authorities claimed that these levels could not be sustained. Between 1970 and 1984 environmental pressures have resulted in the withdrawal of 1.8 million acres of hardwood forest from production. The consequence of this, and other restrictions, will be to reduce saw and peeler log availability by the year 2000 by over one million cunits (i.e. to about the present supply level) (Duncan 1986). I expect there would be the same proportional reduction in the pulpwood harvest (i.e. giving a total hardwood harvest of 1.8 million cunits by the year 2000). I also expect that the hardwood harvest will decline even further after the year 2000.

It seems certain that Australia will remain a net importer until well after the year 2000.

## NEW ZEALAND

Until a short time ago, the most authoritative, and comprehensive prediction of plantation supply was that of Elliott and Levack 1981. They predicted that New Zealand has limited scope for increasing production before 1990. The harvest could increase to around 8.5 million cunits after the year 2000. These figures have now been revised and new estimates (see Table 5) predict that the increases will be lower than formerly expected. The harvest just after the year 2000 is now expected to be 7.7 million cunits per year. Some authorities (e.g. Allison 1984) present evidence that suggests even the revised predictions are too optimistic.

Very few pruned logs are currently available. Supplies will slowly increase and volumes are expected to exceed 1 million cunits soon after the year 2000.

Major uncertainties make predictions difficult:

1. Will present levels of new planting be maintained, especially given recent Government tax changes which positively discriminate against new forest planting and restocking?

2. What rotations will be adopted, especially now that economics now favour longer, ratner than shorter, rotations?

My view is that new planting rates will fall and that rotations will lengthen. Projected yields are therefore probably on the high, rather than the low, side.

On one supply aspect there is total agreement. Supplies from indigenous forests will diminish to negligible amounts in the near future.

New Zealand will be an increasing exporter of wood, but for the next 10 years any increase will be relatively small. The big increase will not come until after the turn of the century and that depends on new planting rates being maintained.

## CHILE

Although Chile has more radiata pine than New Zealand, the advantage is limited to stands less than 10 years old. Chilean forestry practice is going through a revolution. The emphasis is changing from pulpwood to sawn timber. Pruning was the exception 5 years ago, but it is now standard practice. To capitalise on this quality improvement, rotations will have to be lengthened from around 24 years to 30 years or more.

In 1984 the Chileans published comprehensive projections of future yield (see Table 6 for the predictions assuming rotation lengths of 24 and 28 years). Our company has been looking at this (as have some Chilean organisations) and our analysis

Table 5.--Projections of future wood supply

New Zealand - Plantations Only

| Product | Average Annual Yield Forecast for Periods (in million cunits) | | | | |
|---|---|---|---|---|---|
| | 1986-90 | 91-95 | 96-00 | 01-05 | 06-10 |
| Pruned logs | 0.1 | 0.4 | 0.7 | 1.2 | 1.4 |
| Total sawlogs | 2.3 | 2.5 | 3.9 | 5.1 | 6.1 |
| Pulpwood | 0.6 | 0.8 | 1.0 | 1.4 | 1.5 |
| Total | 3.0 | 3.7 | 5.6 | 7.7 | 9.0 |

Source: Levack (1986) (pers. com)

Table 6.--Projections of Future Wood Supply

Chile - Radiata Pine Plantations Only

| | | Mean Annual Yields (million cunits) for periods | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 83-85 | 86-88 | 89-91 | 92-94 | 95-97 | 98-00 | 01-03 | 04-06 |
| Main Scenario (24 yr rotation) | Sawlogs | 2.9 | 2.9 | 3.8 | 3.7 | 4.5 | 9.3 | 8.8 | |
| | Pulp | 1.3 | 1.6 | 2.7 | 3.5 | 3.1 | 5.3 | 4.2 | |
| | Total | 4.2 | 4.5 | 6.5 | 7.2 | 7.6 | 14.6 | 13.0 | 13.8 |
| Totals for 28 yr rotation scenario | Total | 3.5 | 3.8 | 4.1 | 5.0 | 6.5 | 9.3 | 11.9 | 19.7 |

Source:

CORFO-INFOR 1984 Values for the 24 year rotations from the table accompanying Graph No. 2 (page 45). Values for 28 year rotation from the table accompanying Figure No. 1 (page 56), also total value for 2004-06 on a 24 year rotation.

leaves us in no doubt that the published Chilean projections are very optimistic. Our own projections are not yet complete but they suggest that the Chilean yield for the rest of this century will be very similar to that which Levack (1986) now forecasts for New Zealand. Chile will have to wait until the next century before she can capitalise on her expanded planting programme.

## DISCUSSION

The data presented above is based on projections. There are doubts about many aspects and about what will actually happen. Some important aspects are:

### Data Accuracy

There are doubts about whether all the plantations claimed to exist do in fact exist. Yield forecasts, despite recent advances, are not always reliable. Silviculture alone can affect the volume produced in New Zealand by 25% or more. The trend to lower stockings will improve financial returns but lower overall yields.

### Tree Quality

Rarely is tree quality taken into account in projections. Silviculture, site and genetics can affect tree size and quality, and therefore, end use. Apart from a division between sawlogs and pulpwood this aspect is generally ignored in all projections. Quality (and economic) considerations have major implications on rotation length. The trend is towards longer rotations.

### Environmental Pressure

This will certainly influence wood availability from indigenous forests in Australia and, to a lesser extent, New Zealand. It may influence plantation supplies as well. This aspect does not appear to have been given the consideration it warrants.

### Locational and Industrial Considerations

Some plantations are remote and may not be harvested when planned. This could affect future projections. Some industries (say, a new pulpmill) need continuous large supplies of raw material before they can begin production. Capital, energy, infrastructure, and markets have to be organised before new ventures can begin. These factors will tend to delay harvest. These projections usually ignore forest ownership, another factor which could delay development.

## CONCLUSIONS

The evidence does not support a belief that the three South Pacific Rim countries are soon to produce vast additional volumes of wood which will flood the world market. All three countries appear to have limited potential increases in production before 1990. Even by the year 2000 the increased volume production potential may not be great.

Australia will be a net importer of wood well beyond the end of this century.

Even when the potential production for New Zealand and Chile are combined, the additional volume available in the year 2000 will probably only be in the range of 7 to 10.5 million cunits.

I repeat that I believe the real threat to northern hemisphere producers from southern hemisphere plantations is much more from the technology of plantation management, than from increased volumes of low cost wood.

That plantation technology offers much more of an opportunity than it does a threat.

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# THE PULP AND PAPER INDUSTRY IN THE NORDIC COUNTRIES IN AN ERA OF INCREASING INTERNATIONAL COMPETITION[1]

Kari Pesonen[2]

## INTRODUCTION

I am very pleased to have this opportunity to discuss the pulp and paper industry in the Nordic countries. During the last ten to fifteen years, the global pulp and paper industry has experienced considerable changes due to fluctuating exchange rates, increasing oil prices, new producers and consumers, etc.

The Nordic countries, where the importance of the pulp and paper industry sector is among the highest in the world, have been strongly challenged to meet these changing conditions in such a manner that this key industry could survive and even prosper.

I will divide my presentation into five parts:

1 Nordic countries and the role of forest industries to their economies.

2 Role of the Nordic countries in global pulp and paper markets.

3 Changing international market conditions for pulp and paper products.

4 Changes in pulp and paper industry structure in the Nordic countries.

5 Competitiveness of the Nordic pulp and paper industry.

I will concentrate on Finland, Sweden and Norway. Denmark is a part of the European Economic Community (EEC) and has completely different resources and problems. I will also leave Iceland out as its raw material base does not support the production of pulp or paper products. Additionally, I will concentrate on pulp and paper industry only as the importance of this sector within the forest industries in the Nordic countries today is clearly most important.

## COUNTRY PROFILES FOR THE NORDIC COUNTRIES

### Land and People

The expression, Nordic countries, usually refers to Finland, Sweden, Norway, Denmark and Iceland. The often used expression, Scandinavia, actually does not include Finland which only belongs to the expanded expression Fenno-Skandia. Finland, Sweden and Norway, where the production of pulp and paper in the Nordic countries is concentrated, are located between 55 and 70 degrees Northern latitude. As can be seen from Figure 1 this geographical location suggests a climate hardly suitable for the production of forest products. The influence of the warm Gulf-stream, however, has resulted in a climate far warmer than geographics alone suggest.

To give a general idea of the Nordic countries, some basic indicators of the people and the country have been summarized into Table 1. In this table, the population in millions, GDP in USD billions and forest area in millions of hectares are presented. To make comparisons somewhat easier also, some per capita figures are presented.

- The total population of the Nordic countries is only some 17 million, but the land area is considerably large (Sweden is the fourth largest, Finland the fifth, and Norway the sixth largest country in Europe). As a result, the number of inhabitants per square kilometre is low (only some 20 compared to 163 in the EEC countries). For reference, the USA has slightly higher number than the Nordic countries with 25 (31 excluding Alaska) but Canada has one of the lowest figures in the world with only 3 inhabitants per square kilometre.

- The Nordic countries have a very high standard of living measured as GDP per capita. It was 12 000 USD in 1984 compared to 7000 USD as the EEC average. For reference, the income per capita in the USA was about 16 000 USA and in Canada some 13 000 USD. The magnitude of the total GDP compares roughly with Canada.

- The forest area in the Nordic countries is considerable compared to population and the average forest area per capita is 3 hectares compared to less than 0.2 in the EEC countries. For reference, the forest area per capita in the USA is about 1 hectare per capita but in Canada a substantial 12. The total forest area in the Nordic countries (52 million hectares) exceeds that of the EEC-10 (34 million) but is small compared to the USA (298 million) or Canada (314 million).

The above facts about the Nordic countries can be summarized as follows:

- a small population with a large land area
- high standard of living
- a lot of forests.

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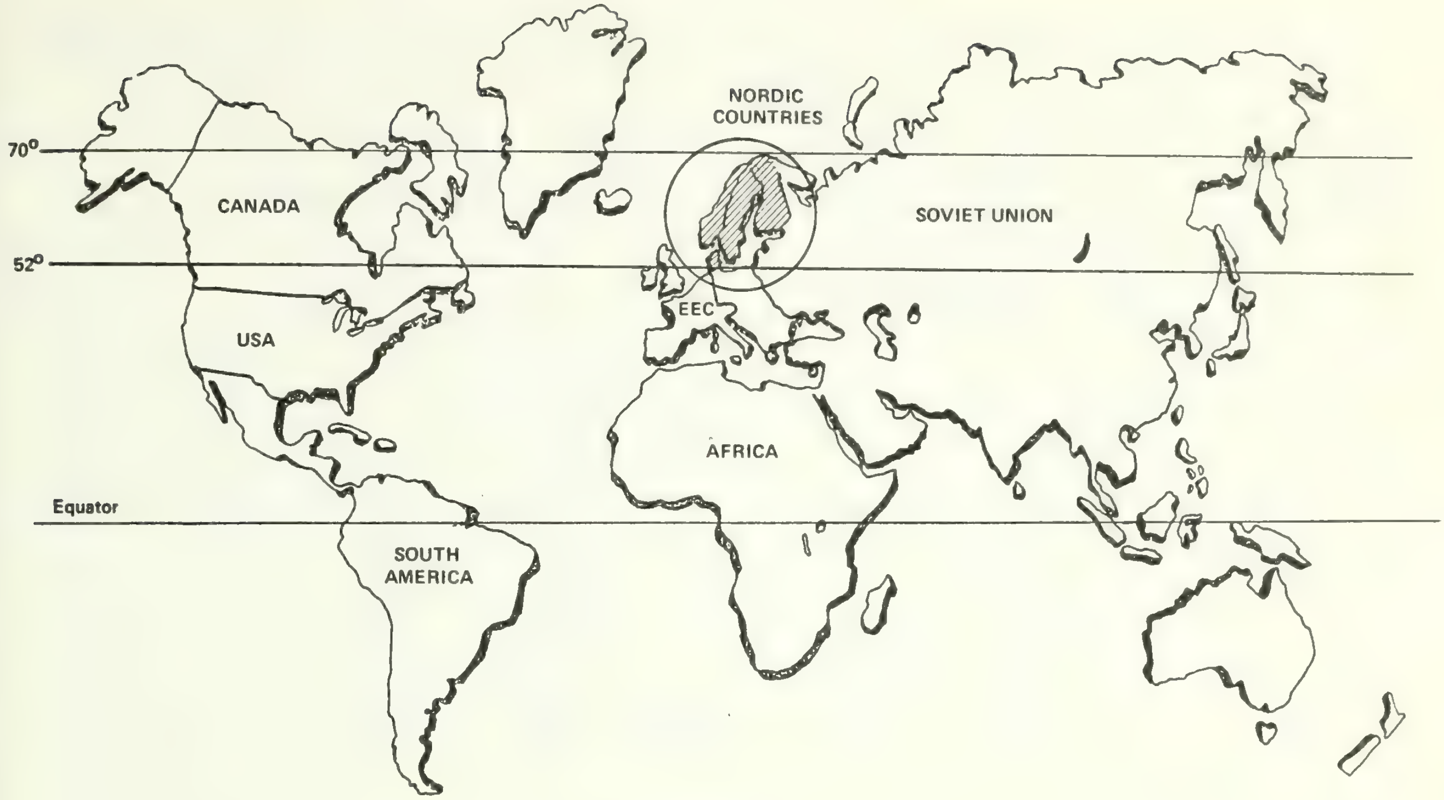



Figure 1

PROFILES OF THE NORDIC COUNTRIES COMPARED TO WESTERN EUROPE AND NORTH AMERICA

| | POPULATION (MILLIONS) | TOTAL GDP (BILLION USD) | TOTAL FOREST AREA (MILLION HA) |
|---|---|---|---|
| NORDIC COUNTRIES | 17 | 212 | 52 |
| EEC–10 | 273 | 1934 | 34 |
| USA | 239 | 3841 | 298 |
| CANADA | 25 | 342 | 314 |

| | INHABITANTS/ SQUARE KILOMETRE | INCOME USD/CAPITA | FOREST AREA HA/CAPITA |
|---|---|---|---|
| NORDIC COUNTRIES | 16 | 12 000 | 3.0 |
| EEC–10 | 165 | 7000 | 0.15 |
| USA | 26 | 16 000 | 1.2 |
| CANADA | 3 | 13 000 | 12.4 |

Table 1

## Role of Forest Industries to the Economy

Due to their small population, the manufacturing industries in the Nordic countries soon found their domestic markets limiting and were forced to seek export markets. This trend has continued and is clearly seen in Figure 2 where the share of exports as percent of the GDP for the Nordic countries is presented in 1970 and 1984.

o The share of exports as percent of the GDP in the Nordic countries is very high and has grown clearly since 1970.

o The share of exports is highest in Norway where they accounted for almost half of the GDP in 1984. For Norway, however, crude oil has had a decisive role in this development.

o In Finland and Sweden export revenues accounted for more than 30 % of the GDP in 1984 compared to some 25 % in 1970.

o For reference, in the USA the share of exports is less than 10 %, but in Canada exports accounted for almost as much as in the Nordic countries.

Looking closer at the exports (Figure 3) in 1970 and in 1984 it can be concluded that:

o The share of forest products as percent of total exports has declined in the Nordic countries. This does not mean, however, that forest industries had not grown but rather that other industries such as the metal and chemical industries in Finland and Sweden and the oil industry in Norway have simply grown faster.

o The importance of the forest industry is highest for Finland where it accounts for almost 40 % of export revenues. In Sweden, the share of forest products is today already less than 20 % and in Norway only some 5 % of total exports.

o For reference, the share of forest industry of total exports in the USA is only 3 % but in Canada it accounts for almost 15 % of all exports.

The role of the forest industry in the Nordic countries can be summarized as follows:

o The importance of forest products to the economy is clearly biggest for Finland. For Sweden, it is today the number two industry and for Norway its importance is relatively small.

o Export of paper in the Nordic countries has grown faster than that of other forest products making it the most important export product of the Nordic forest industry today.

## ROLE OF THE NORDIC COUNTRIES IN WORLD PULP AND PAPER TRADE

### Share of Markets and Main Products of the Industry

The share of the Nordic countries of world production of pulp and paper is illustrated in Figure 4:

o The share of the Nordic countries is about 14 % in pulp production and 8 % in paper production.

o North America has clearly the highest capacity of both pulp and paper.

o The share of the Nordic countries of pulp exports is about 24 % and 31 % of paper exports.

o North America dominates exports of market pulp.

o Western Europe is an important exporter of paper with a 24 % share of world exports.

The importance of the Nordic countries is considerably bigger in world exports than in world production. Together with North America, the Nordic countries still dominate exports of market pulp and together with North America and Western Europe the exports of paper.

The production of main pulp and paper grades in the Nordic countries is presented in Figure 5:

o Sweden is the biggest producer of pulp within the Nordic countries with a production of some 9 million tons in 1984 followed by Finland with close to 8 million tons.

o Norway is clearly least significant with a production less than 2 million tons in 1984.

o Bleached kraft pulp is the most important chemical pulp for Finland and Sweden. Sweden produces mostly softwood kraft whereas Finland also has a sizeable hardwood kraft production.

o The share of other chemical pulps including unbleached kraft and sulphite pulps is considerable in Sweden due to higher share of industrial paper grades of total paper production but small in the other Nordic countries.

The paper production in the Nordic countries can be summarized as follows:

o Finland is the biggest producer of paper with a production of 7.5 million tons in 1984 followed by Sweden with 7 million tons.

o The production of paper in Norway was less than 2 million tons in 1984.

o The share of newsprint of total paper production in Finland and Sweden was about 20 % and equivalent to over 1.5 million tons for each in 1984. In Norway the production of newsprint was only some 0.8 million tons but accounted for 60 % of total paper production.

o Printing and writing papers accounted for close to 50 % of paper production in Finland with 3.5 million tons whereas in Sweden their share was only about 20 % with slightly over 1 million tons.

o The share of industrial papers including sack paper, linerboard bleached board, etc. accounted for over 50% of paper production in Sweden with close to 4 million tons of production

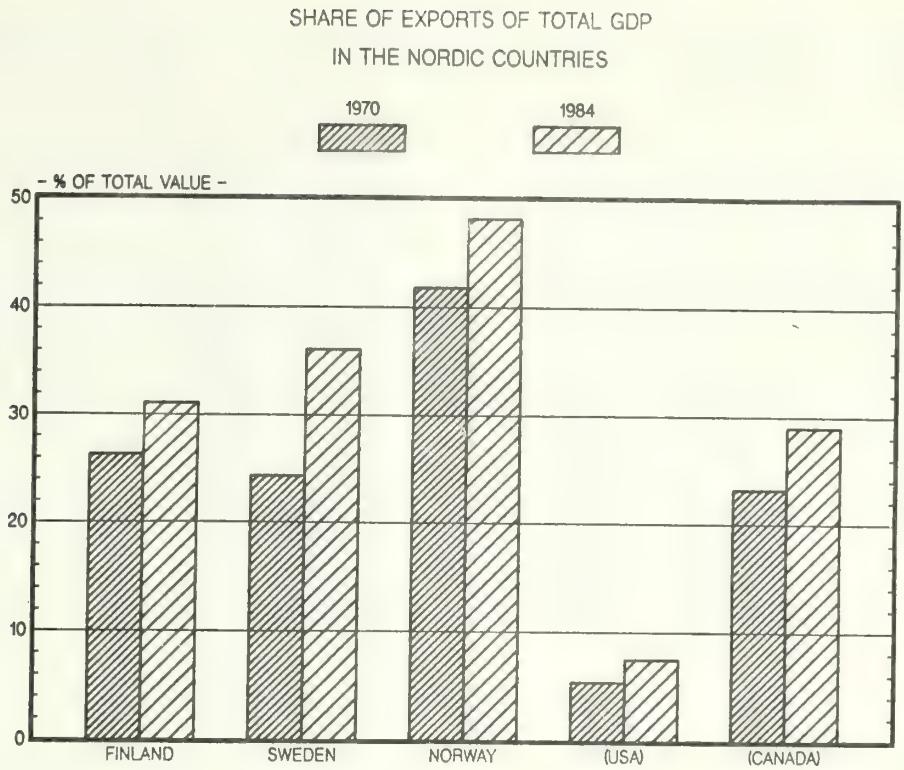



Figure 2

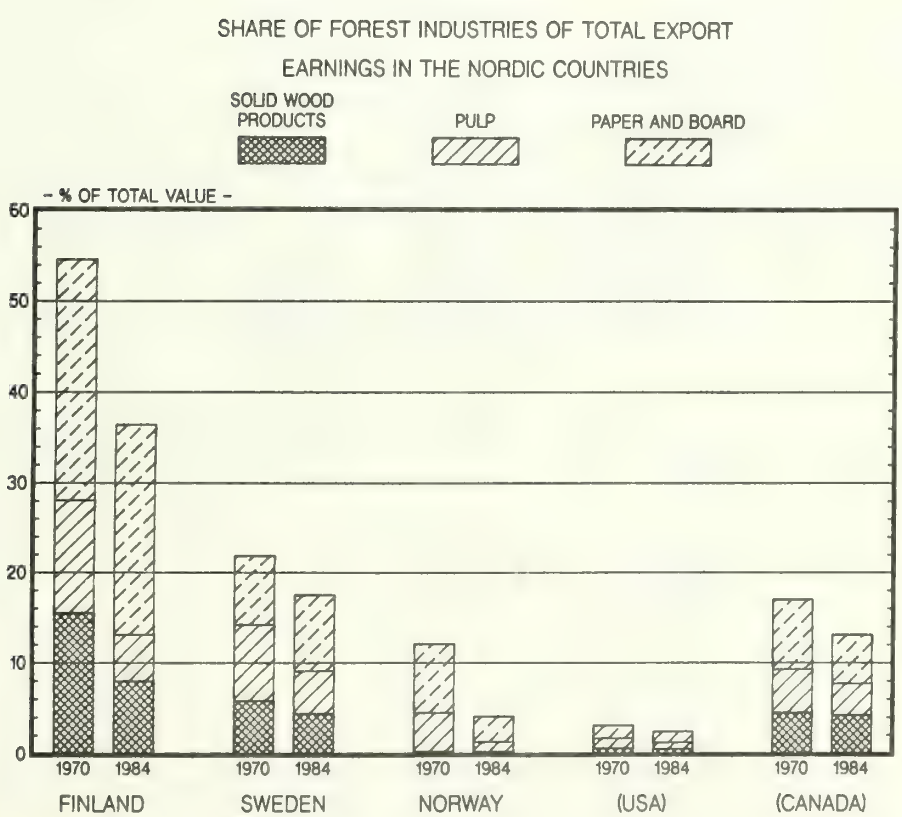



Figure 3

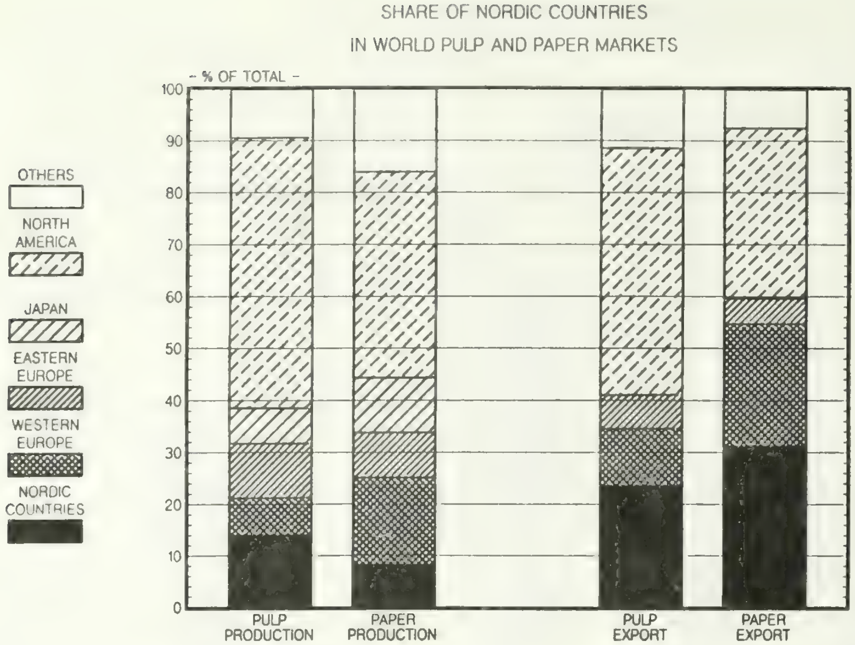



Figure 4

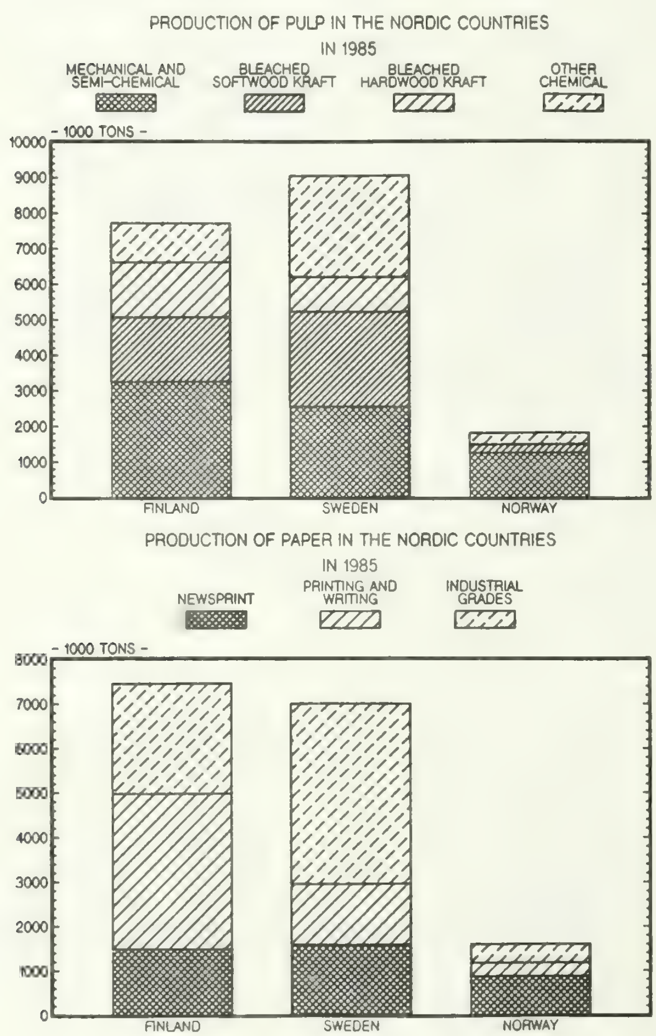



Figure 5

in 1984. In Finland their production totalled about 2.5 million tons but was only about 30 % of production.

Finland and Sweden are clearly the most important producers of pulp and paper among the Nordic countries. The product mix between the Nordic countries for both pulp and paper differs considerably as Finland produces printing and writing paper, Sweden mostly industrial grades and Norway newsprint. Because the demand for pulp in the Nordic countries is mostly created by the countries own paper mills it is logical that the differences in produced pulp grades result mainly from differences in paper mix.

## Main Markets

The main markets of pulp and paper for the Nordic countries are presented in Figure 6:

o The majority of the pulp production in the Nordic countries is used in integrated paper mills.

o The volume of exports is about 4.8 million tons representing about 25 % of total pulp production.

o Western Europe represents the main market for pulp exports with a volume close to 4 million tons or about 80 % of exports.

o Other markets for pulp are marginal with a total volume of about 1 million tons. Oceania and Asia are most important among them.

The paper markets can be summarized as follows:

o Domestic markets account for only 21 % of total production of paper.

o Also for paper, Western Europe is the most significant export market with an export volume close to 9 million tons or 72 % of exports.

o Australia and Asia are the second most important export markets for paper from the Nordic countries with a volume of 1.5 million tons.

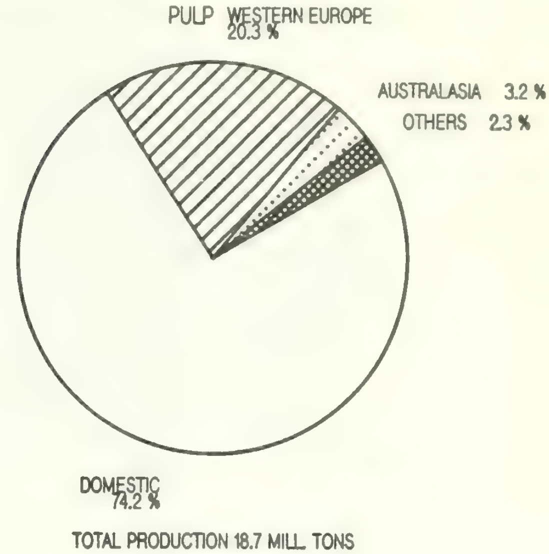
o North America and especially the USA has increased in importance considerably during the last years and this market today takes 6 % of the paper exports with a volume close to 1 million tons.

The markets of the Nordic pulp and paper industry can be summarized as follows:

o The majority of the pulp production is consumed domestically and the remainder is exported to Western Europe.

o Domestic markets only absorb 20 % of the paper production and the majority of paper is exported to Western Europe. Markets outside Western Europe have, however, increased in importance.

MAIN MARKETS FOR PULP AND PAPER PRODUCTION OF THE NORDIC COUNTRIES



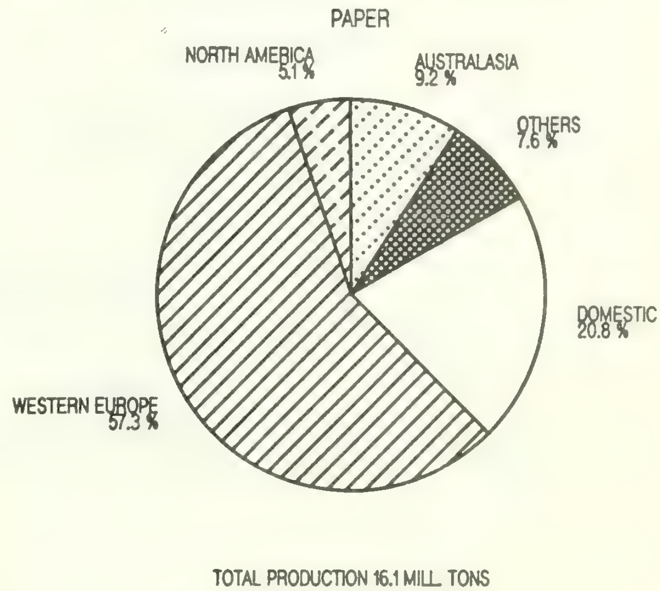




Figure 6

## Main Competitors

The competitors of the Nordic countries are discussed mainly on the Western European markets as this market clearly dominates in importance for both pulp and paper exports.

The market shares of main competitors for selected pulp and paper grades are presented in Figure 7 and Figure 8. The following can be concluded:

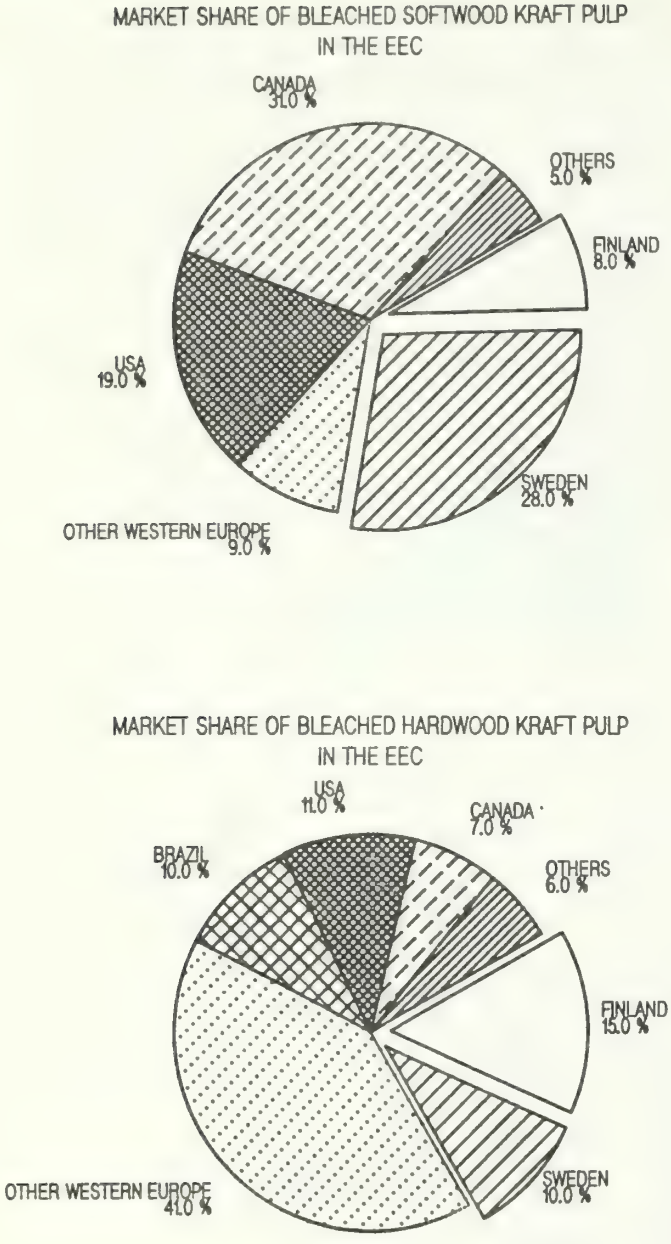



Figure 7

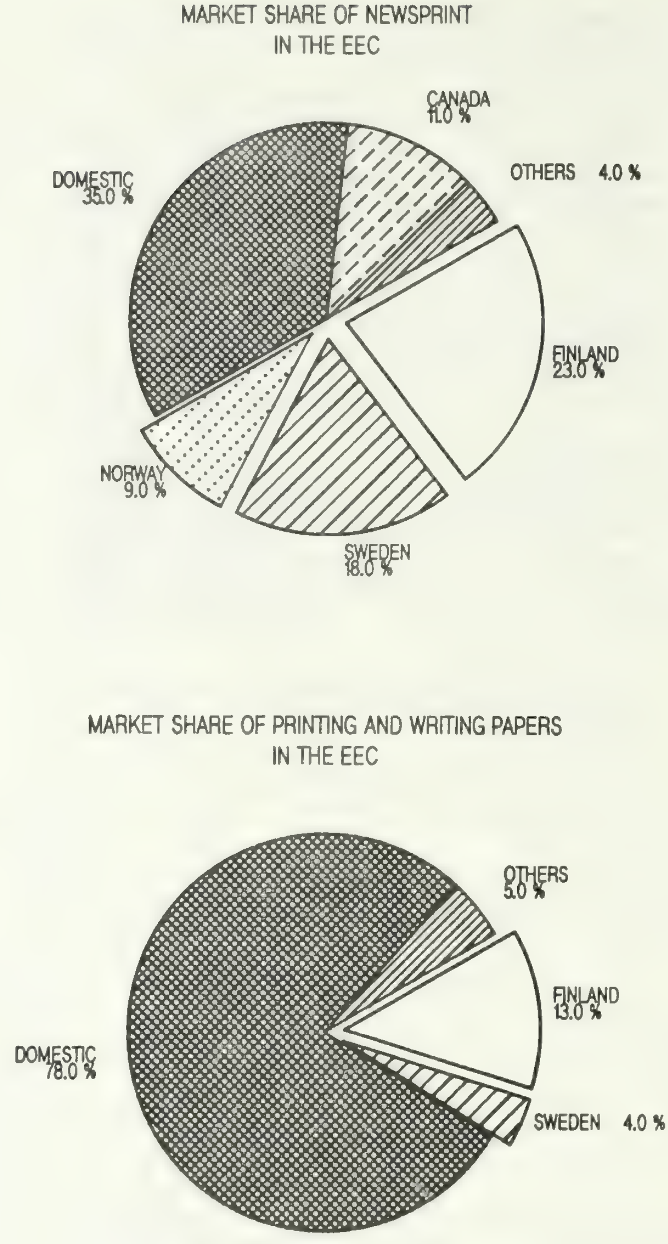



Figure 8

o The Nordic countries together with the USA and Canada are the most important suppliers of softwood chemical pulp to Western Europe. The Nordic countries and especially Finland and Sweden are main competitors to each other.

o For bleached hardwood kraft pulp the domestic supply from Spain and Portugal is the most important. The Nordic countries compete also against each other and Canada, USA and Brazil.

o All Nordic countries are important producers of newsprint and supply about 50 % of the Western European demand. The competition stems largely from domestic producers but also Canada is an important competitor in Western Europe.

o For printing and writing papers, Finland and Sweden compete against each other for some grades but are relatively small compared to the main competition from local producers.

## CHANGING INTERNATIONAL CONDITIONS

The markets for pulp and paper like the whole world trade have experienced considerable changes during the last fifteen years. Among the most important changes affecting the pulp and paper industry have been:

- o fluctuating exchange rates.
- o increasing energy prices.
- o new producers.

## Exchange Rates

The exchange rates of world currencies remained fixed until 1971 when the Bretton Woods agreement was signed (Figure 9). Until then the US dollar was fixed to the price of gold, and the exchange rates of foreign currencies were adjusted periodically only if there was a need for it. Since, the exchange rates started to fluctuate in 1971:

o The US dollar depreciated against the European currencies up until 1980. This had a negative influence for the pulp and paper industry in the Nordic countries as most of their products were traditionally invoiced in US dollars.

o Since 1980, the development was reversed and a dramatic appreciation of the US dollar was experienced in the world. This was very beneficial for the pricing of the Nordic pulp and paper producers and improved the cost competitiveness to such extent that exports to the US markets became economically feasible.

o Since 1985, the US dollar has, however, again reversed its development and has depreciated against most industrialized currencies and has again applied cost pressures for the pulp and paper producers in the Nordic countries.

## Energy Prices

The prices of energy have experienced dramatic changes during the last fifteen years influencing the whole world economy. We have all in a very concrete fashion experienced the effects of rising oil prices in the 1970's. The rising oil prices have also influenced the price development of other fossil fuels such as natural gas.

Of the Nordic countries, Finland and Sweden have no oil, gas or coal deposits of significance within their boundaries while Norway has developed big reserves of oil in the North Sea. The rising oil prices have consequently had an opposite effect for Norway than for Finland and Sweden.

The pulp and paper industry which is an energy intensive industry was strongly challenged by the rising oil prices both in Finland and in Sweden. The dramatic price development of crude oil since 1973 is illustrated in Figure 10 in US dollars:

o The oil price in US dollars increased a substantial 42 % p.a. during 1974-1980 to 35 USD/barrel.

o The appreciation of the Nordic currencies against the US dollar partly reduced the effect up to 1980.

o Since 1980, the price of oil decreased slightly to USD 28/barrel, but the appreciation of the US dollar created still strong increases in local currencies.

o Since 1985, the dramatic drop in oil prices together with a depreciating US dollar have completely reversed the situation.

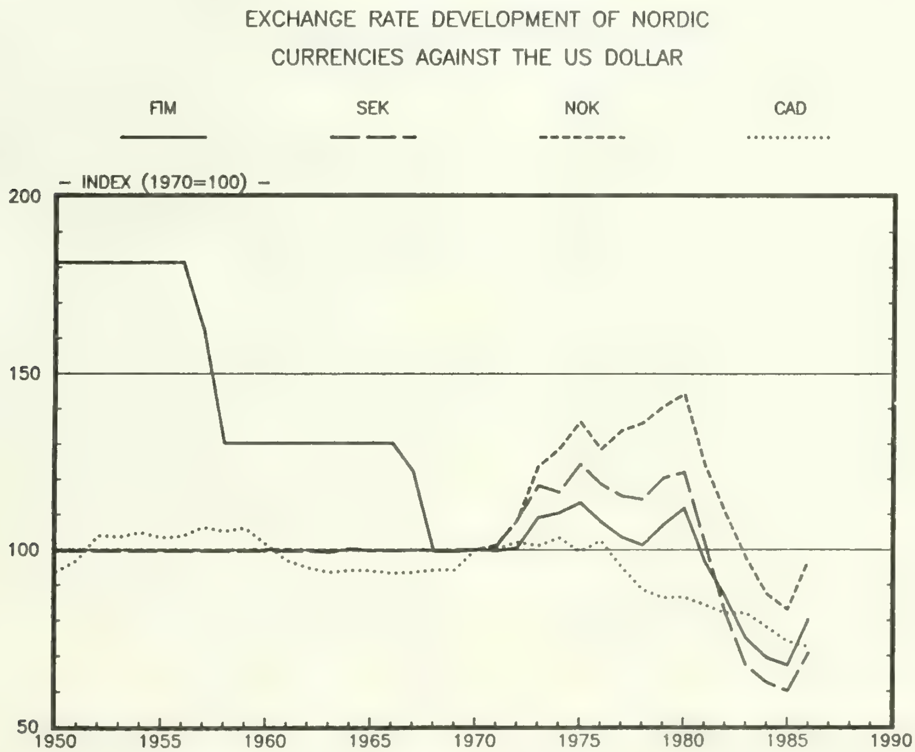



Figure 9

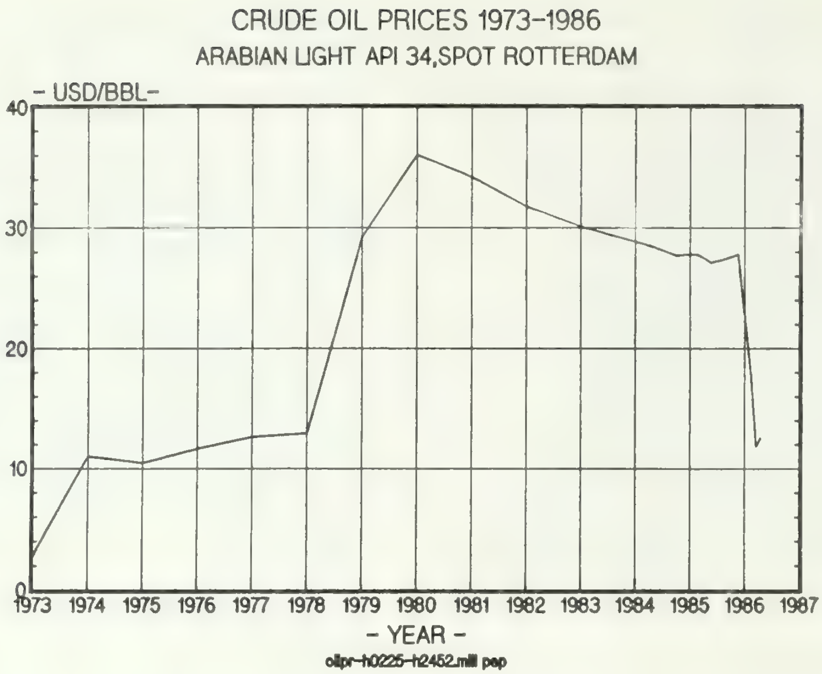



Figure 10

## New Producers

The supply of both pulp and paper has experienced considerable changes during the last fifteen years. New producers have appeared on both domestic and export markets of several grades changing the overall market picture.

This development has been especially dramatic for bleached hardwood kraft market pulp. In Figure 11, the development of the market shares for main producers of this grade are illustrated during 1965-1985.

The following conclusions about the development can be drawn:

o Producers in Latin America, mostly Brazil and in the Southern Europe, in Spain and Portugal, have initiated a massive production of bleached hardwood kraft from eucalyptus plantations since the 1970's. This wood which produces a low cost, high quality pulp has had a tremendous impact on the global pulp markets.

o The share of the Latin American and Southern European producers today is close to 40 % of the market for bleached hardwood pulp compared to slightly over 10 % in 1965.

o The North American producers have kept their market share whereas producers in the Nordic countries have integrated into paper production and have seen their 35 % market share in 1965 decline to about 15% in 1985.

The production of chemical market pulp where the cost of wood raw material is decisive for profitablilty has begun its shift to southern regions where huge plantations guarantee availability and the favourable climate results in astonishingly

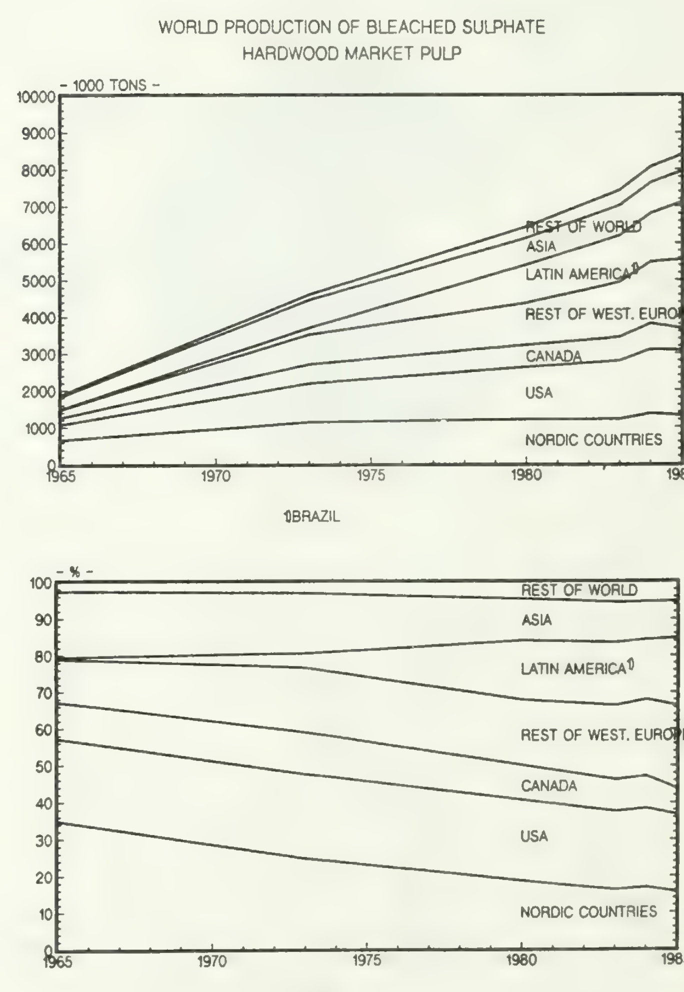



Figure 11

fast growth and consequently low cost of wood. This trend will continue in the years to come as production is expanded and new applications for eucalyptus pulps are developed. This will place a strong challenge for the market pulp producers in the Northern parts of the world.

## CHANGES IN THE NORDIC PULP AND PAPER INDUSTRY

### Markets

As previously discussed, the Nordic pulp and paper industry has its main market in Western Europe for most pulp and paper grades. Due to changing international conditions, however, also other markets have become attractive. Good example of this has been the rapidly growing demand for pulp and paper products in the Asia. Another example is the US market which became attractive due to the appreciation of the US dollar since 1980. In Figure 12, the exports of the Nordic countries to the USA are illustrated during 1970-1985. The annual growth rate in the 1980's has exceeded 20 %. The following can be concluded about the development:

o The increase in exports has been very rapid and the level today is close to 0.8 million tons.

o Newsprint exports have reached a level of 200 000 tons in 1985. Norway and Sweden are the major forces behind increased exports of newsprint.

o Exports of printing and writing papers to the USA were close to 0.5 million tons in 1985. Finland is the major force for these grades constituting close to 80 % of the Nordic exports.

o The exports of industrial grades from the Nordic countries have remained at marginal levels, most of them coming from Sweden.

It must be, however, remembered that although the Nordic producers constitute a considerable portion of the off-shore imports, they are still small compared to the total paper imports of close to 9 million tons or total paper consumption of 65 million tons in the USA. For certain higher quality paper grades where the market volume is limited the importance of the Nordic producers has been of significance.

It remains to be seen how the recent depreciation of the US dollar against the Nordic currencies will influence export incentive to the USA. Several Nordic pulp and paper companies have expressed their determination to stay on the US markets and the export continues at about the same rate, although certain grades such as SC and LWC paper have seen a slackening of demand.

### Production

#### Product Mix

In the production of pulp and paper, the share of fiber cost of total costs varies considerably between different grades as illustrated in Figure 13 where cost structure of bleached softwood kraft and woodfree fine paper is presented. As previously discussed, the Nordic pulp and paper industry has faced increasing competition for products where the share of fiber cost is high such as chemical pulp. This has forced the industry to integrate into papermaking, to develope new products such as SC (supercalendered) paper and to invest in products where the cost competitiveness is better. In Figure 14, the share of market pulp of total pulp production is demonstrated for Finland and Sweden:

o The share of market pulp of total pulp production has decreased significantly during the last twenty years.

o Finland has decreased its dependence on softwood market pulp from 64 % in 1965 to 28 % in 1985 and Sweden from 85 % in 1965 to 65 % in 1985. Sweden is thus still more dependent on softwood market pulp.

o In hardwood pulp, Finland has decreased dependence from 85 % in 1965 to 48 % in 1985. For Sweden, the development is even more dramatic as the dependence on hardwood market pulp in 1965 was 97 % compared to 57 % in 1985. Also in hardwood pulp, Sweden is more dependent on market pulp than Finland.

In addition to higher degree of integration, the Nordic countries have invested in paper products where the share of expensive fiber is lower. In Figure 15, the product mix of paper production in Finland and Sweden is demonstrated:

o The share of cultural papers including newsprint and printing and writing papers has increased in both countries.

o The share of cultural papers has increased considerably in Finland, from 53 % in 1965 to 67 % in 1985. Sweden which has traditionally had a lower share of cultural papers has also experienced the same development. The increase has, however, not been as dramatic as in Finland, from 37 % in 1965 to 42 % in 1985.

The pulp and paper industry in Finland and Sweden have significanlty decreased their dependence on market pulp by integrating into papermaking. Both countries, and especially Finland, have changed their product mix in the increasing competitive markets and have invested heavily in the production of cultural papers, and consequently they account for the majority of paper produced in Finland today and approach the 50 % market also in Sweden.

### Production Inputs

The production costs of pulp and paper differ considerably by product, but usually the most important cost elements are fiber, energy and labor.

#### Fiber

Due to the Northern geographical location, the growth of wood in the Nordic countries is clearly slower than in most competing regions. This is

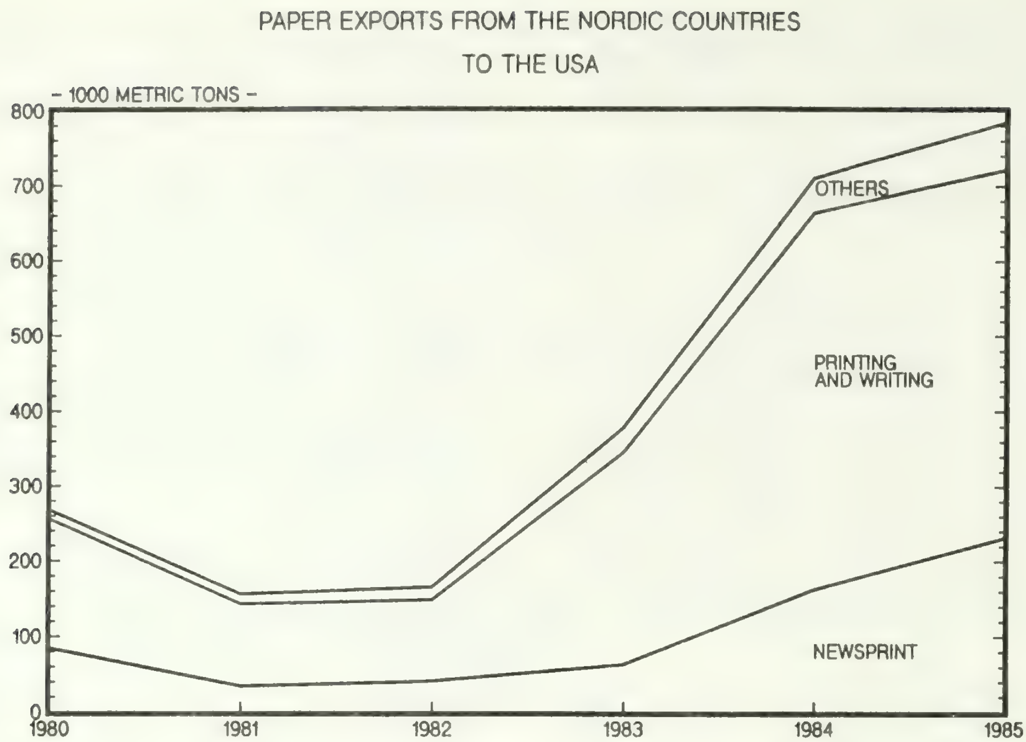



Figure 12

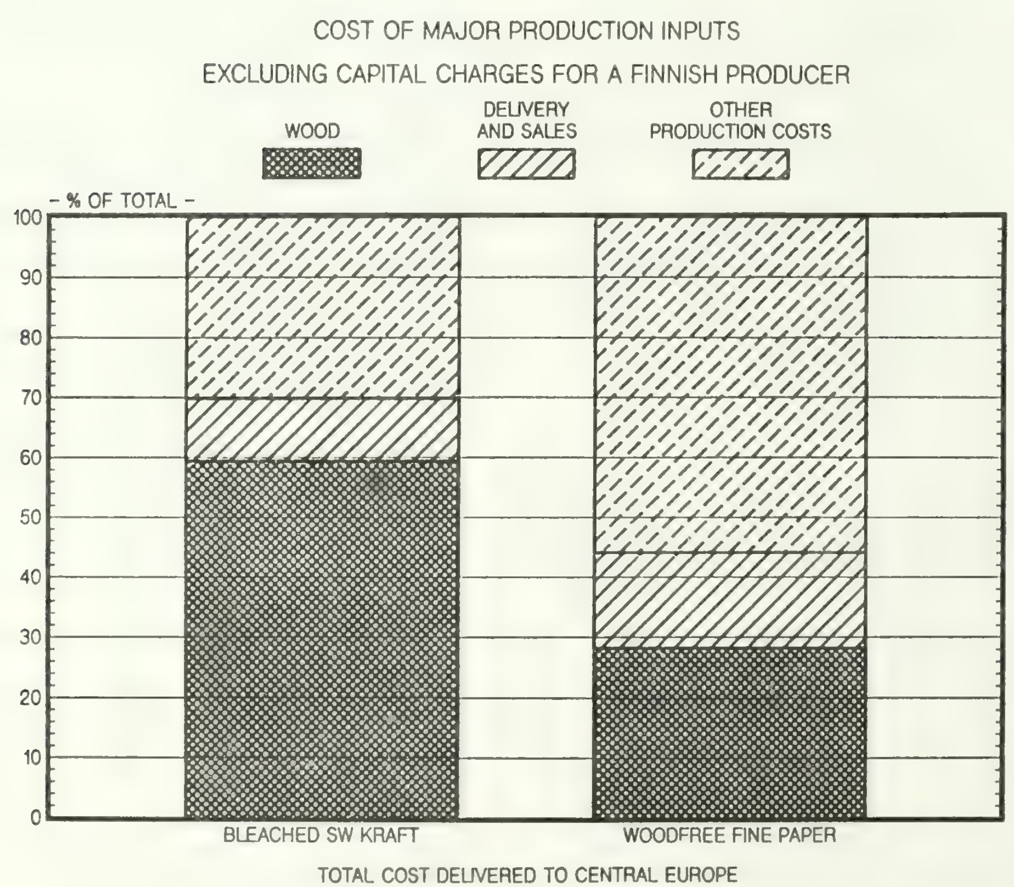



Figure 13

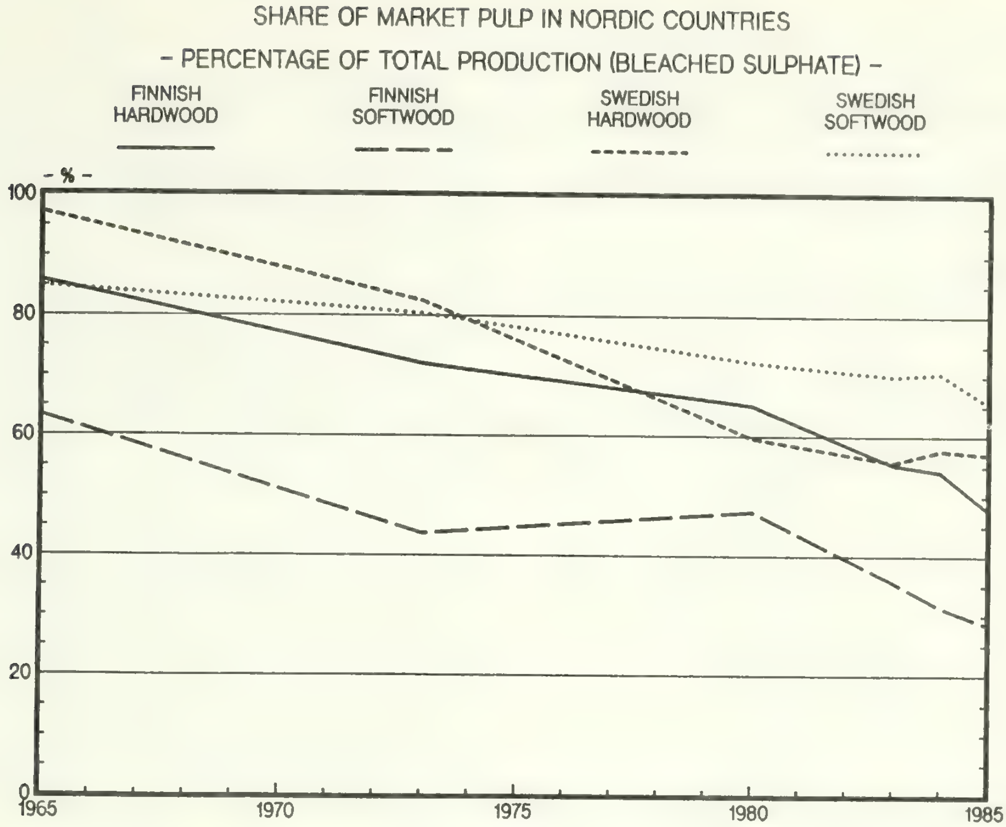



Figure 14

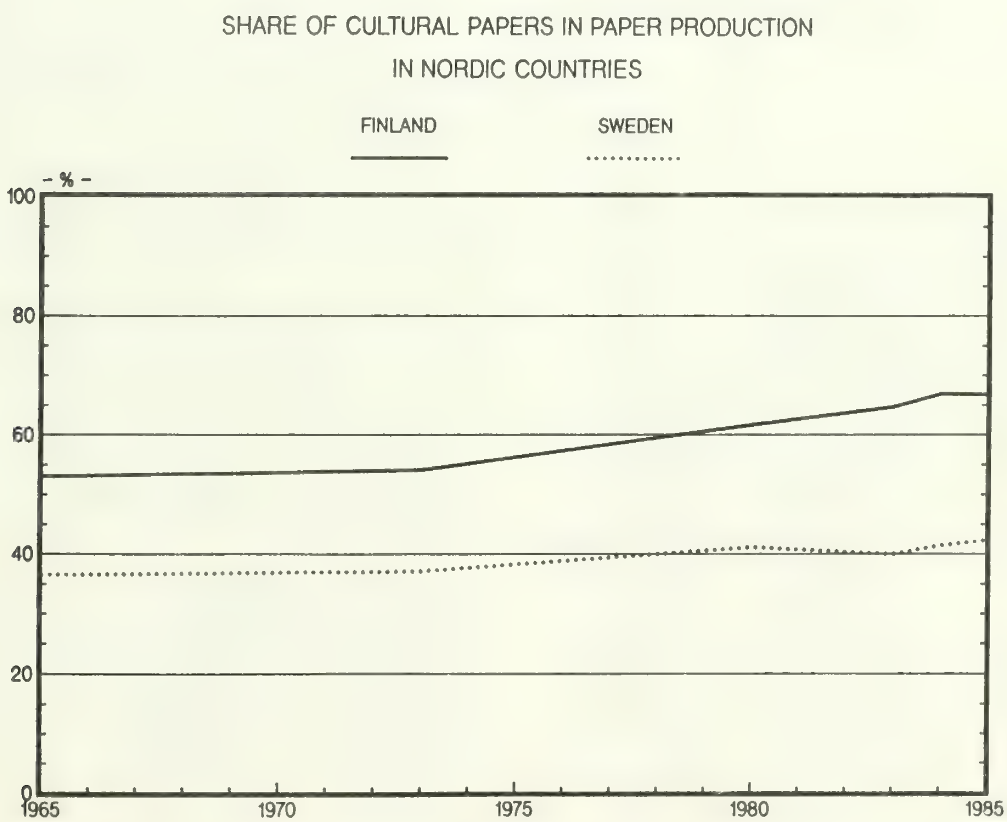



Figure 15

one of the key factors resulting in higher wood costs than in the competing regions as illustrated in Figure 16. To compensate this, the Nordic mills have developed new mechanical pulps such as thermo-mechanical pulp (TMP) and pressurized groundwood pulp (PGW) which enable usage of more economical fiber mix for several paper grades.

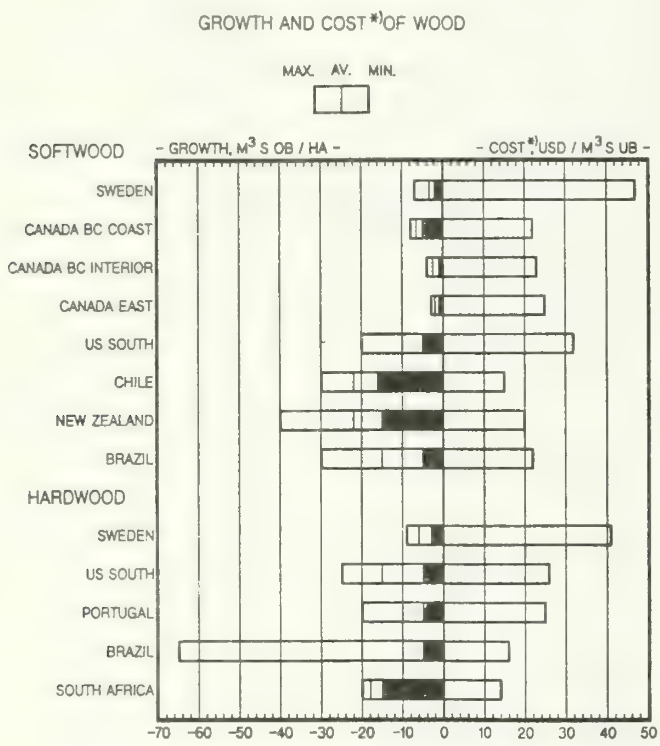



Figure 16

## Energy

The Nordic countries must import most of their fossil fuels, and the prices consequently follow international price trends as described in previous section. This low self-sufficiency is a disadvantage as the pricing usually takes place in US dollars and transportation and other costs must be added to the basic costs. As a result of expensive cost of fossil fuels, the pulp and paper industry in the Nordic countries has been forced not only to look for alternative fuels but also to reduce consumption of outside fuels (Figure 17). As a result of continuous energy savings and improved recovery systems, the Nordic pulp and paper industry today consumes less outside fossil fuels per product than any other country in the world.

The cost of power, which is one of the most important cost elements in the production of mechanical pulps, is cheap in international comparison in Sweden and Norway as demonstrated in Figure 18. This low price is a result of high share of cheap hydro power and nuclear energy of total energy generation.

## Labor

The labor costs in the Nordic countries are expensive compared to several EEC countries in Western Europe. In North America the labor costs are, however, clearly higher than in the Nordic countries. The high share of fringe benefits of total labor costs is a special feature of the Nordic countries.

To compensate higher labor costs, the Nordic pulp and paper industry has always tried to take advantage of the economy of scale as demonstrated in Figure 19. The average size of new paper machines in the Nordic countries has clearly exceeded that of the rest of the world.

## Size of Companies

The Nordic pulp and paper industry has experienced considerable changes in product mix, markets and structure of production of capacity. Another important development in the Nordic pulp and paper industry is the increasing concentration of the production (Figure 20):

o The decline in the number of companies is dramatic as in 1970 there were a total of 129 pulp and paper companies in the Nordic countries compared to 72 in 1986.

o The number of pulp and paper companies in Finland today is 20 compared to 30 in 1970.

o In Sweden the number of pulp and paper companies today is 26 compared to 42 in 1970.

o The decline has been biggest in Norway where several small mechanical pulp mills have beeen united into bigger units.

The increasing production of pulp and paper in the Nordic countries together with a smaller number of companies has resulted in a considerable increase in average company size:

o The average size of companies today is biggest in Finland with an average capacity of 750 000 tons per company. Sweden is second with 620 000 tons per company and Norway third with 130 000 tons per company.

o The increase has been biggest in Finland and Sweden where the average output of pulp and paper companies has more than doubled during 1970-1985.

The pulp and paper industry in the Nordic countries has experienced considerable changes in ownership during the last fifteen years. Smaller units have been merged into bigger units to take advantage of economy of scale and to reduce domestic competition. The size of companies is still smaller than in North America, and it appears likely that more restructuring will still take place in the next couple of years to establish internationally competitive units.

## SHARE OF OIL OF TOTAL HEAT GENERATION IN SWEDEN

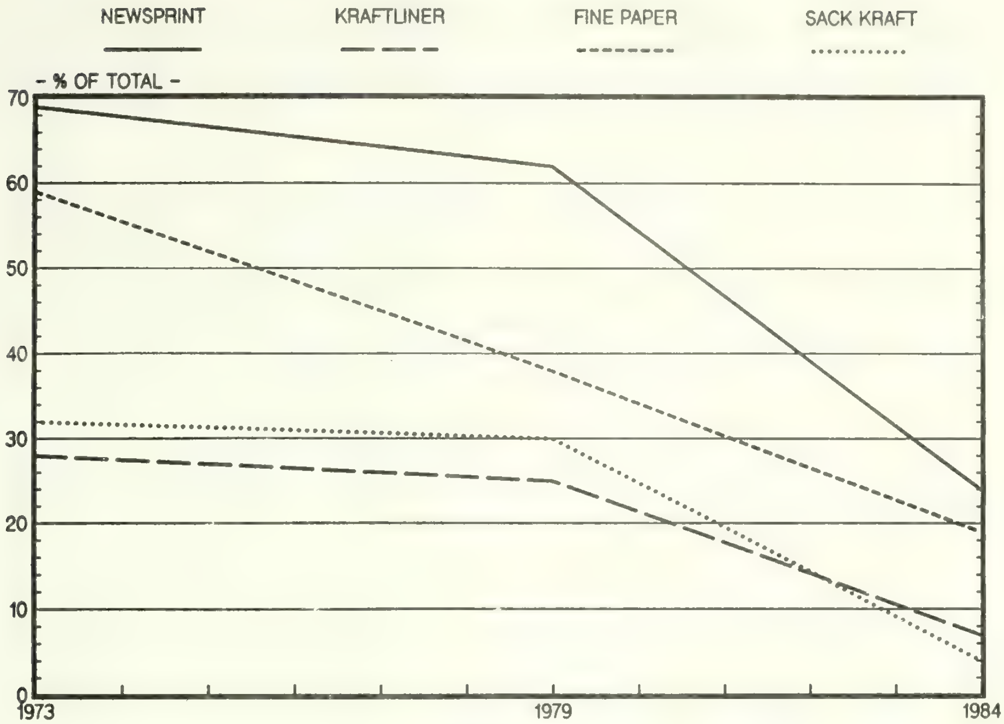



Figure 17

## PURCHASED POWER PRICE REGIONAL AVERAGE

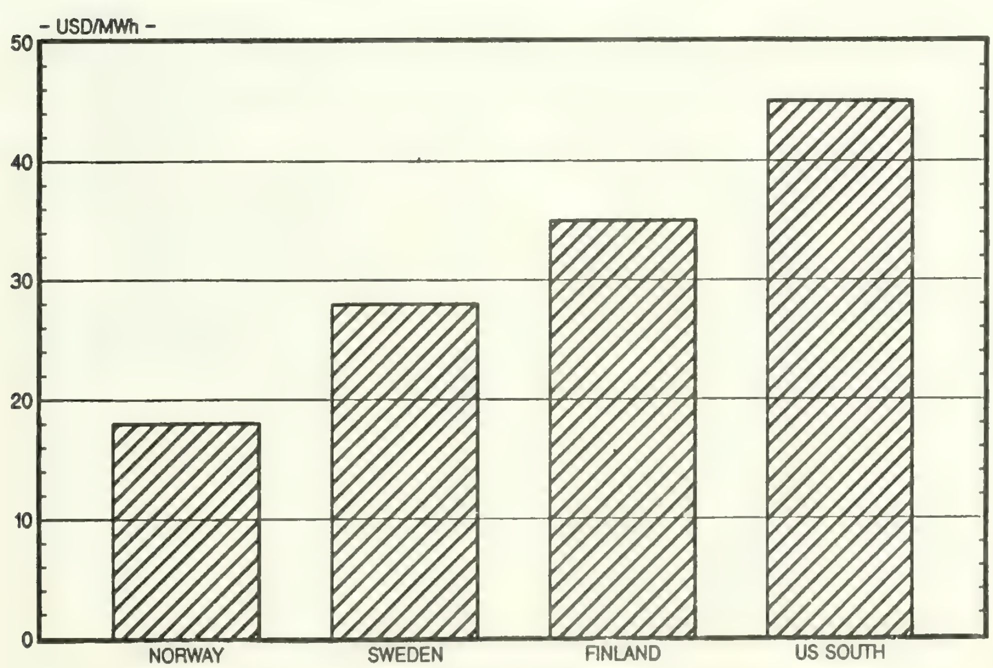



Figure 18

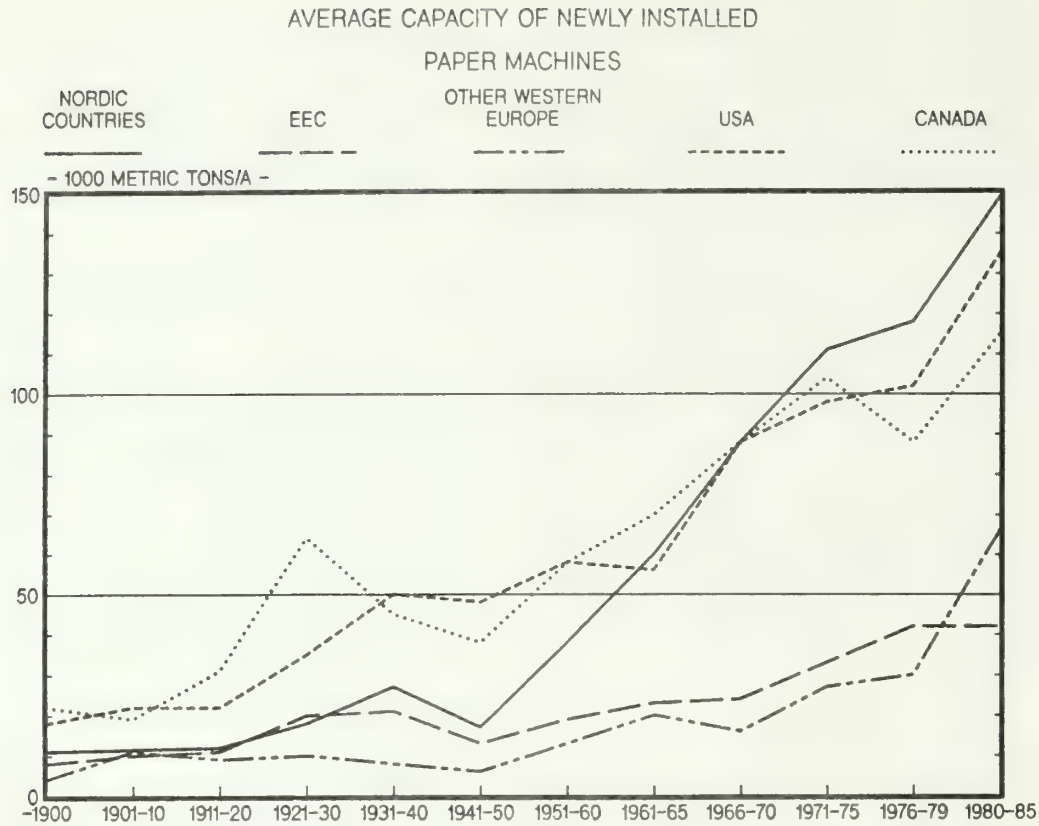



Figure 19

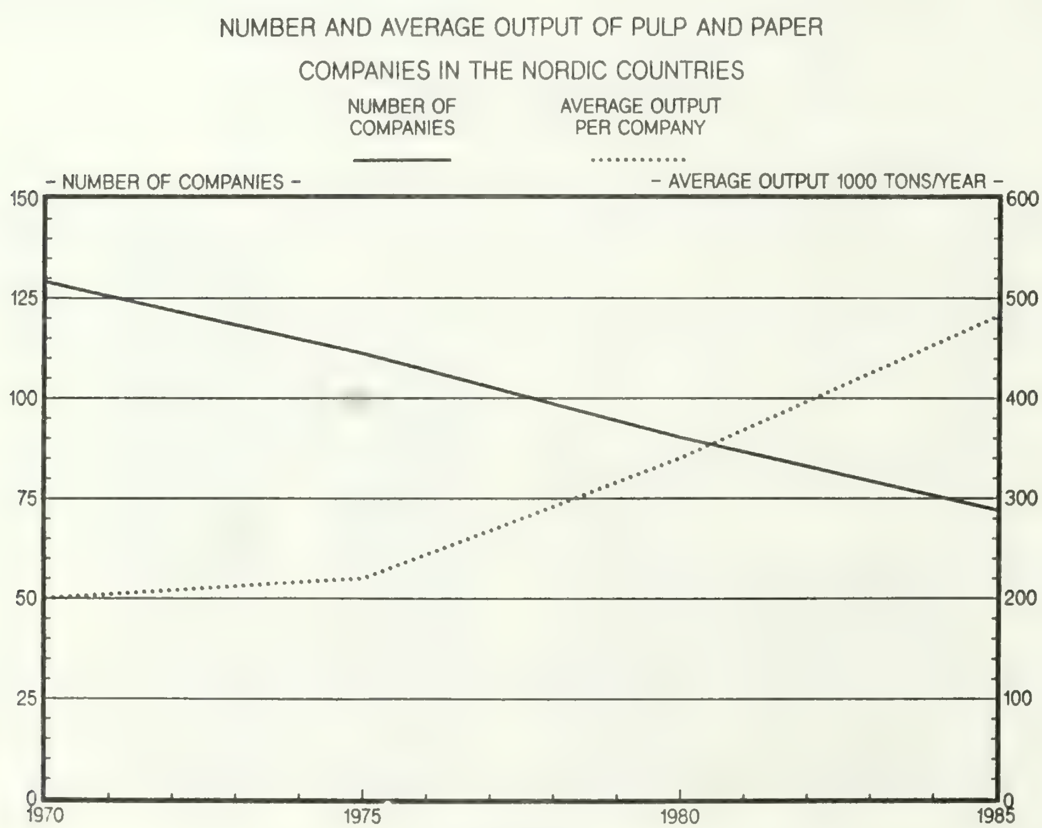



Figure 20

## COMPETITIVENESS OF THE NORDIC PULP AND PAPER INDUSTRY

The competitiveness of any industry can be measured in several ways, but in industries where the products do not substantially differ from one another the comparison of manufacturing costs is one of the most interesting ones.

### Size of Paper Machines

As previously discussed, the pulp and paper industry in the Nordic countries has invested in bigger paper machines than the competing regions. This is clearly illustrated in Figure 21 where the average size of existing paper machines for selected countries is presented:

o Finland has the biggest existing paper machines with an average capacity of over 70 000 tons per year followd by Sweden with over 60 000 tons. This is very high compared to EEC where the average size still is less than 20 000 tons per year.

o Norway has clearly smaller machines than Finland and Sweden.

o Canada and the USA also have big machines in international comparison with average capacities of over 50 000 tons.

### Cost Competitiveness

The cost competitiveness i.e. manufacturing costs and delivery costs to Western Europe of the Nordic producers for two different products, namely bleached hardwood kraft pulp and uncoated woodfree paper are presented in Figures 22 and 23. In these figures each graph represents a region and the y-axis shows costs of producers placed in ascending order while the x-axis shows cumulative tonnage of each region.

For bleached hardwood kraft following can be concluded:

o Portugal and Brazil have about 30 % lower costs than Finland.

o Most mills in the US South have also lower costs than the Finnish producers.

For uncoated woodfree paper the conclusions are following:

o The integrated mills in Finland and Sweden are competitive in Western Europe.

o The integrated mills in Sweden appear to have the lowest costs.

o The unintegrated mills in the Nordic countries have higher costs than most other producers.

The cost competitiveness of the Nordic producers clearly illustrates that even the big, modern production units cannot compensate the substantially lower wood costs of the Southern producers for hardwood pulp and the cost competitiveness against them is weak.

For uncoated woodfree paper the situation is reversed and the integrated producers in Finland and Sweden have a clear cost advantage against the unintegrated producers of the EEC.

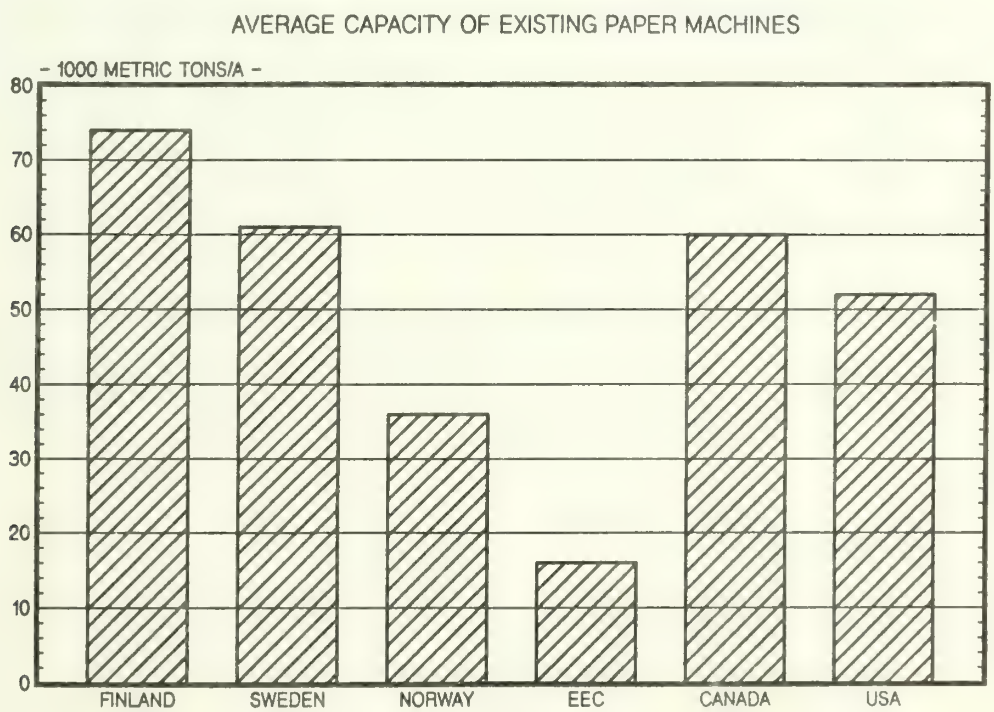



Figure 21

BLEACHED MARKET PULP,HARDWOOD SULPHATE

MANUFACT. AND DISTR. COSTS TO WESTERN EUROPE,COST LEVEL 1986/II

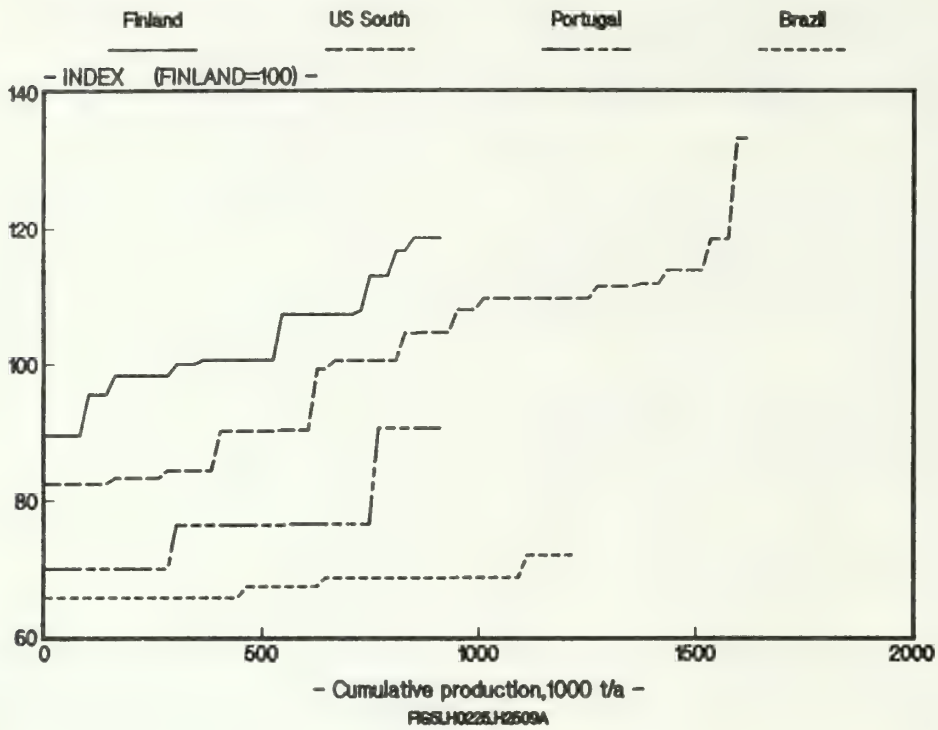



Figure 22

WOODFREE UNCOATED PAPER

MANUFACT. AND DISTR. COSTS TO WESTERN EUROPE,COST LEVEL 1986/II

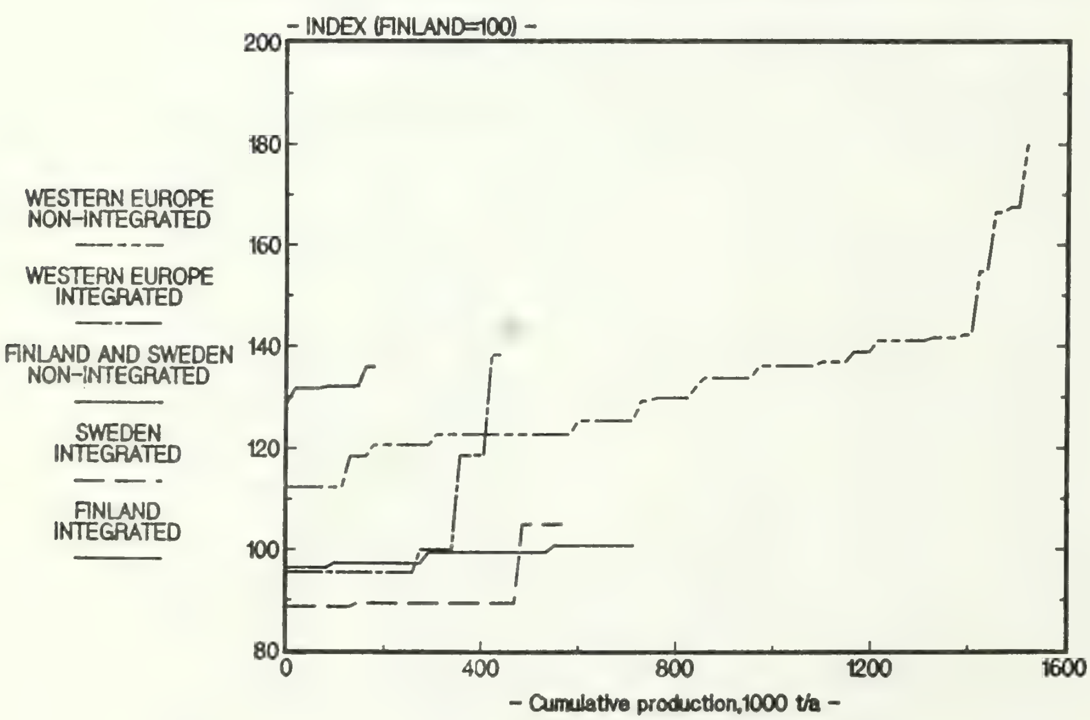



Figure 23

## CONCLUDING REMARKS

The Nordic countries where the importance of the pulp and paper industry to the national economy is among the highest in the world have been strongly challenged to meet the changing international conditions during the last fifteen years.

The industry has gone through several changes concerning industry structure, energy efficiency, product mix, markets etc. Among the most important changes are the following:

o The pulp production in the Nordic countries has been increasingly integrated into paper production. This has been especially true for hardwood kraft pulp where new producers with substantially lower production costs have emerged on the markets.

o The share of cultural papers where the share of fiber cost is less important have grown at the expense of industrial papers.

o The Nordic producers have looked at new markets such as the Far East to take a share of the rapid growth of pulp and paper consumption. Increasing marketing efforts have also been aimed at the USA which has been attractive due to the strong US dollar.

o Fiber costs have been decreased as a result of new mechanical pulps developed in the Nordic countries such as the TMP and PGW.

o Considerable investments in energy conservation have made the Nordic pulp and paper industry the most energy efficient in the world.

o The new paper machines in the Nordic countries have been bigger than in competing regions resulting in lower manhours per ton of end product.

o The Nordic pulp and paper industry has also experienced considerable restructuring which is still in progress. The result of this development is the bigger size of companies which enables more efficient units and greater rationalization of production.

The pulp and paper industry in the Nordic countries today can be considered as a leader in the world with modern and cost efficient production units. Its importance to the national economies will remain important for many years to come, but in order to keep its leading position on the key markets in Western Europe integration into papermaking shall be further increased and new paper products are developed where full advantage of the competitive advantages such as the low power rates and big production units can be taken.

## Pine Regeneration

Moderator:

Benton H. Box
Clemson University

# SLASH PINE PLANTATION SPACING STUDY--AGE 30[1/]

Earle P. Jones, Jr.[2/]

Abstract.--In 1952, slash pines (Pinus elliottii Engelm. var. elliottii) were planted at spacings of 6x6, 6x8, 5x10, 8x8, 6x12, 10x10, 7.5x15, and 15x15 feet on an old field (site index 65 feet at age 25) in the middle Coastal Plain of Georgia. Except for a few trees removed to salvage ice damage, plots were not thinned. Merchantable volumes at ages 25 and 30 did not differ significantly among original spacings. Recommendations are: (1) For pulpwood production, plant 600-800 trees per acre and harvest at age 25. (2) For sawtimber, plant 600-700 trees per acre and thin at age 15 to 20, or plant 400 to 600 and delay thinning until after age 20.

## INTRODUCTION

Most studies of pine plantation spacings have incorporated some cultural treatment, such as fertilization or thinning, when the trees attained merchantable size. Although thinnings are certainly warranted in most pine plantations, it is interesting to see how slash pine (Pinus elliottii Engelm. var. elliottii) responds to eight spacings, unaltered by thinning or any other cultural activity. Early results of this study were reported after 8 years (Bennett 1960) and 12 years (Harms and Collins 1965). Interim growth information derived from the study has been included in other reports (Bennett 1963 and 1975). Results through age 30 are reported here.

## METHODS

The study site was an old field, which had been cultivated the previous year, on the Holt Walton Experimental Forest in Dooly County, Georgia, in the middle Coastal Plain. The soil is loamy sand, mostly of the Lakeland and Gilead series. In January 1952, nursery-run 1-0 slash pines from the Georgia Forestry Commission nursery at Albany, Georgia, were planted. The study was laid out in plots of approximately 0.8-acre with a 12-foot wide firebreak around each plot. Two blocks were established, with each of the eight spacings represented in each block. Spacings were precisely measured in NS and EW directions, and planting spots were marked with a peg prior to arrival of the seedlings. Seedlings were dibble-planted under careful supervision over a 2-day period when soil moisture was plentiful. The few dead seedlings found in inspections were replaced in March and May of 1952, and resulting overall survival at the end of four growing seasons was 97 percent. Eight spacings were installed: 15x15, 7.5x15, 10x10, 6x12, 8x8, 5x10, 6x8 and 6x6 feet (table 1). These spacings represent densities from 194 to 1210 trees per acre (TPA). Hardwoods and shrubs were never a problem on this recently cultivated study site, and the few invading stems that did appear, including volunteer pines, were removed.

## MEASUREMENTS

Since age 12, measurements have been taken on permanent interior measurement plots of approximately 0.37 acre. Measurements were made annually until age 22, then at ages 25, 28, and 30. At these times, d.b.h. was measured and crown class and mortality were noted of all trees on the sample plot. Total heights and live crown ratios were measured on no less than 20 randomly selected trees proportionally representing the 1-inch diameter classes encountered.

Diameter distributions, height data, and plot dimension information were combined to generate stock and stand tables by 1-inch diameter classes for total and merchantable cubic-foot volume, basal area, mean total heights of all trees and the dominant stand, and other stand parameters.

For each treatment plot, by year, a height-diameter relationship was fitted to the form:

$$\text{Log } H = a + b\ (D)^{-1} \qquad (1)$$

where: Log = common logarithm, base 10,
H = total height (feet),
D = diameter breast height (0.1 inch), and
a and b = calculated coefficients.

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1/ Paper presented at Fourth Biennial Southern Silvicultural Research Conference Atlanta, Georgia, November 4-6, 1986.

2/ Research Forester, USDA Forest Service, Southeastern Forest Experiment Station, Macon, Georgia.

Table 1.--Various stand characteristics averaged for each original spacing treatment, by selected ages

| ORIGINAL SPACING (FEET) | TREES PER ACRE | AGE (YEARS) 10 | 15 | 20 | 25 | 30 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Survival, all trees (percent) | | | | | Basal area, all trees (sq. ft./acre) | | | | |
| 15x15 | 194 | 95 a[1/] | 87 a | 86 ab | 82 a | 76 a | 44 f | 71 d | 95 d | 110 d | 114 b |
| 7.5x15 | 387 | 94 a | 91 a | 87 a | 81 ab | 73 ab | 71 e | 103 c | 122 c | 134 c | 136 a |
| 10x10 | 436 | 91 a | 86 a | 83 abc | 72 bc | 60 bc | 76 e | 109 c | 132 bc | 140 bc | 135 ab |
| 6x12 | 605 | 91 a | 85 a | 77 abc | 66 c | 55 c | 88 d | 116 c | 132 bc | 138 bc | 132 ab |
| 8x8 | 681 | 96 a | 92 a | 84 abc | 71 bc | 58 c | 94 cd | 131 b | 149 a | 151 abc | 140 a |
| 5x10 | 871 | 96 a | 86 a | 78 abc | 63 c | 48 c | 103 bc | 131 b | 146 ab | 146 abc | 133 ab |
| 6x8 | 907 | 94 a | 86 a | 75 c | 60 c | 45 c | 113 ab | 143 ab | 155 a | 154 ab | 134 ab |
| 6x6 | 1210 | 95 a | 88 a | 76 bc | 64 c | 49 c | 117 a | 146 a | 158 a | 160 a | 144 a |
| | | Mean d.b.h., all trees (inches) | | | | | Mean crown ratio, all trees (percent) | | | | |
| 15x15 | 194 | 6.6 a | 8.8 a | 10.2 a | 11.2 a | 12.0 a | 69 a | 54 a | 44 a | 35 a | 31 a |
| 7.5x15 | 387 | 6.0 b | 7.3 b | 8.1 b | 8.9 b | 9.4 b | 59 b | 46 b | 36 b | 27 b | 26 b |
| 10x10 | 436 | 5.9 b | 7.3 b | 8.2 b | 9.1 b | 9.7 b | 56 bc | 44 bc | 35 b | 27 b | 25 bc |
| 6x12 | 605 | 5.4 c | 6.4 c | 7.2 c | 7.9 c | 8.5 c | 54 bcd | 42 cd | 31 c | 25 c | 24 bc |
| 8x8 | 681 | 5.1 cd | 6.2 cd | 6.9 cd | 7.6 cd | 8.1 cd | 51 cd | 38 de | 30 c | 23 d | 22 cd |
| 5x10 | 871 | 4.7 e | 5.6 e | 6.3 e | 7.0 d | 7.6 d | 49 d | 36 ef | 31 c | 24 cd | 23 cd |
| 6x8 | 907 | 4.9 de | 5.8 de | 6.5 de | 7.2 d | 7.8 cd | 48 de | 35 ef | 29 cd | 22 e | 20 d |
| 6x6 | 1210 | 4.3 f | 5.0 f | 5.6 f | 6.1 e | 6.6 e | 44 e | 32 f | 27 d | 21 e | 20 d |
| | | Mean total height, D+C, (feet) | | | | | Merchantable volume (cu. ft./acre) | | | | |
| 15x15 | 194 | --[2/] | 48 ab | 59 a | 67 a | 71 a | 573 c | 1506 c | 2562 b | 3392 a | 3720 a |
| 7.5x15 | 387 | -- | 49 ab | 59 a | 66 a | 70 ab | 935 ab | 2160 b | 3208 a | 3942 a | 4364 a |
| 10x10 | 436 | -- | 48 ab | 58 ab | 66 a | 70 ab | 977 ab | 2272 ab | 3444 a | 4110 a | 4247 a |
| 6x12 | 605 | -- | 46 abc | 55 abc | 62 ab | 67 abc | 1056 a | 2233 ab | 3145 a | 3795 a | 3962 a |
| 8x8 | 681 | -- | 46 ab | 55 abc | 62 ab | 66 abc | 1034 a | 2489 ab | 3549 a | 4102 a | 4129 a |
| 5x10 | 871 | -- | 45 bc | 53 c | 60 b | 64 cd | 962 ab | 2280 ab | 3246 a | 3734 a | 3757 a |
| 6x8 | 907 | -- | 45 bc | 54 bc | 62 ab | 66 bc | 1166 a | 2559 a | 3593 a | 4120 a | 3925 a |
| 6x6 | 1210 | -- | 43 c | 51 c | 57 b | 60 d | 747 bc | 2168 ab | 3158 a | 3682 a | 3697 a |

1/ For given ages and characteristics, treatment means followed by the same letter do not differ significantly at the 5 percent level.

2/ Crown class not recorded at age 10.

Height estimates for each diameter class on a given plot were used in calculating cubic-foot volume estimates by these equations:

$$MCFV = .002575(D^2H) - .4588 \quad (2)$$

$$TCFV = .002668(D^2H) - .128974 \quad (3)$$

$$TCFV_{<4.6} = .00595(D^2H) - .88985 \quad (4)$$

where: MCFV = Merchantable cubic-foot volume, o.b. to 4 inches top d.o.b.,

TCFV = Total cubic-foot volume o.b.,

$TCFV_{<4.6}$ = Total cubic-foot volume of trees less than 4.6 inches d.b.h.,

and D and H are as stated above.

Equation (2) was derived from an equation published by Bennett and others (1959) for old-field planted slash pines up to 12 inches d.b.h., but revised to include trees up to 18 inches. This step seemed appropriate because trees up to 15 inches d.b.h. were present at age 30. Equation (3) is also from Bennett and others (1959), and Equation (4) is an unpublished[3/] equation for small diameter trees. Volumes were calculated for each diameter class represented on a given plot, accumulated across classes for a plot total, and converted to per acre equivalents.

Study data were examined by block analysis of variance at five selected ages: 10, 15, 20, 25, and 30 years. Significant differences among spacing treatments were compared by Duncan's multiple range test at the 5 percent level of confidence.

3/ Personal communication with Douglas R. Phillips, Southeastern Forest Experiment Station, Clemson, South Carolina, 1982.

## RESULTS

### Survival

Initial planting densities ranged from 194 to 1210 TPA (15x15 to 6x6). As would be expected, the number of surviving TPA remained directly related to initial density, through age 30, with but a few exceptions. Survival ranged from 91 to 96 percent at age 10 (table 1). A severe ice storm on New Year's Day, 1964, at age 12, caused some top breakage and branch stripping throughout the study. The 6x6 had significantly less damage than all other spacings. Those trees that appeared unlikely to survive were removed to reduce the risk of attack by bark beetles (Ips spp. and Dendroctonus spp.), but removals as a percent of the number of surviving trees on the plots were not significantly different among spacings. By age 15, survival still was not significantly related to initial density and varied from 92 to 84 percent. Significant differences were apparent at age 20, in a range from 87 to 75 percent. By age 30, survival varied from 76 percent on the 15x15 spacing to 45 percent for the 6x8 spacing.

Most early mortality can be attributed to a combination of competition and fusiform rust caused by the fungus Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme. Survival, at least through age 20, was above normal for operational planting and represents very nearly the effect of full stocking at the initial spacing.

### Basal Area

Total basal area has remained directly correlated with original spacing, with few exceptions, through age 25. By age 10 the three closest spacings (5x10 and closer) already had over 100 square feet of basal area per acre, and there was a 73-square-foot range between spacing extremes (table 1). By age 20, the four closest spacings (8x8 and closer) had converged at about 150 square feet, and from age 20 to age 25, they showed little or no increase in basal area. Basal area stocking on all but the two widest spacings culminated at or before age 25. A maximum basal area of 165 square feet was reached on one of the 6x6 plots at age 25. Only the 15x15 and 7.5x15 had not shown a downturn by age 30.

### Diameter Breast High

Quadratic mean diameters of all trees were calculated; they are perhaps 0.1 inch higher than the arithmetic mean. A significant difference in mean diameter first occurred at age 5 at a density of 500 to 550 TPA (Bennett 1960), and means have become increasingly more divergent across the range of densities to age 30. Average diameter of all trees at the widest spacing was 53 percent larger than that at the closest spacing at age 10, and 81 percent larger at age 30 (table 1). The strong effect of planting density on d.b.h. can be seen in the fact that over the 1000-tree range of initial densities in this study, there are five or six significant differences in mean diameter. Two of these differences consistently occur at the two spacing extremes--the 6x6 and 15x15 have significantly smaller and larger diameters, respectively, than all other spacings. At age 20, only the 15x15 spacing had more than half its surviving trees in merchantable sizes, but by age 30 all surviving trees were merchantable at all spacings.

### Crown Ratio

Crown ratio is important in maintaining diameter growth, and it is significantly related to stand density. Assuming a 35-percent crown ratio is desirable in pulpwood size slash pine, the 6x6 spacing was in jeopardy at age 15, with 32 percent of total height in green crown (table 1). At age 20, all spacings 6x12 and closer (over 600 TPA) had less than 35 percent green crown, and by age 25, only the 15x15 spacing still had 35 percent crown.

### Total Height

Mean total height is usually not related to stand density among the densities normally encountered in managed stands of southern pines. This spacing study has been an exception since age 10 (Harms and Collins 1965, Lloyd and Jones 1983). Plots planted closer than 8x8 (681 TPA) generally had significantly shorter trees through age 30 (table 1). Only the very wide and very close spacings were clearly different in height, i.e., fewer than 400 vs. more than 800 TPA.

These height differences also have an effect on the estimation of site index when widely different densities are found on otherwise similar sites. The average height of the dominant stand at age 25 in this study is a direct measure of 25-year site index (table 1), and a 10-foot difference in site index can be recognized due to spacing, while the difference between blocks was not significant. With two overlapping significance ranges by Duncan's test, the difference point can be generalized at 600 TPA surviving at age 10.

Perhaps we should remind ourselves as we are looking for numbers to put into computer models, that site index was not originally intended as an absolute measure of site potential. In fact, site index is usually estimated to the nearest 10-foot class. In that light, variations of less than 10 feet are not serious defects. However, if these eight spacing treatments are assigned to 10-foot site index classes, the three widest spacings will be site 70, and all others site 60.

### Merchantable Cubic-Foot Volume

From ages 10 through 30, there were very few significant differences in merchantable volume production among the eight spacings, but variation among treatments was high (table 1). At age 10, the widest and closest spacings had significantly less volume than the intermediate spacings. At ages 15 and 20, only the 15x15 was significantly below other spacings in cubic

volume. There was considerable variation in cubic volume among treatments at ages 20, 25, and 30 (fig. 1), but the differences at ages 25 and 30 were not statistically significant.

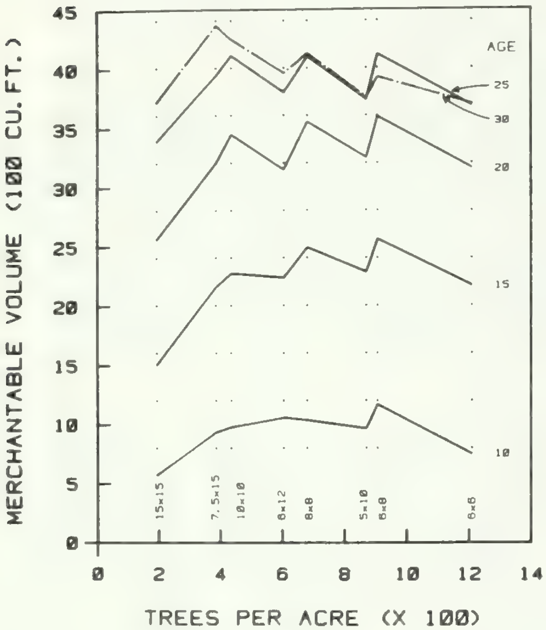


Figure 1.--Merchantable volume over initial trees per acre and spacings, by age, for slash pine spacing study.

These results should be viewed with caution. They represent only the effect of initial TPA (spacing) on volume, and not surviving TPA, which is the product of initial density and current survival percent. Yield studies consistently show a highly significant effect of surviving TPA on cubic volume yields (Bennett 1963).

## DISCUSSION AND CONCLUSIONS

Merchantable cubic-foot volumes at ages 25 and 30 were not significantly different across the eight initial spacings in this study (15x15 to 6x6, 194 to 1210 TPA), but yields for the two extreme spacings were consistently lower than for the others (table 1). However, spacing alone does not account for changes in TPA over time, as a result of mortality. Further investigations with these data will examine effects of TPA on growth and yield. Merchantable volume growth declined sharply after age 25 (fig. 1), especially for spacings of 8x8 and closer (over 680 TPA). For example, the 6x8 spacing (900 TPA) had the highest volume of all spacings at ages 15, 20, and 25, but fell to fifth highest at age 30, when the 7.5x15 spacing had the highest volume. Lacking significant differences in merchantable volume, the choice of initial spacing may therefore be based on other factors.

Average d.b.h. at spacings below 6x12 (less than 600 TPA) were significantly larger than at closer spacings. Average diameters of 10 inches were obtained by age 20 at the widest spacing (200 TPA), which is desirable for early sawtimber production.

Although this study was not designed to compare square vs. non-square spacings, evidence indicates no significant difference in merchantable cubic volume production through age 30 due to spacing configuration. Ten feet or more between rows permits access into the stand, but apparently does not sacrifice merchantable volume production.

Mutual competition was evident in the early decline of live crown ratio at the closer spacings. Crown ratio was approaching 30 percent by age 20 at spacings of 6x12 and closer (over 600 TPA). If sawtimber is the objective, thinnings should be applied by age 20 for stands planted with over 600 TPA. Thinnings in stands starting from fewer than 600 TPA can be deferred until after age 20. Perhaps stands originating with 400 or fewer TPA could go unthinned to age 30. Without thinning, basal area will peak at 150-160 square feet per acre, and then declined due to mutual competition among planted trees.

Several conclusions can be drawn from this study and applied to similar unthinned old-field slash pine plantations on sites 60 to 70:

1. A 6x6 spacing is not efficient for merchantable volume production.

2. Select a spacing pattern to allow 10 to 12 feet between rows.

3. For pulpwood production only, plant 600 to 800 TPA and harvest at age 25.

4. For sawtimber production, plant 600 to 700 TPA and thin at age 15 to 20, or plant 400 to 600 trees and delay thinning until after age 20.

5. On similar sites, unthinned slash pine stands starting from 200 TPA will have dominant stand heights approximately 10 feet taller than plantings originating with 1200 TPA.

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# CONVERTING "THE BARRENS" FROM LOW-QUALITY HARDWOODS TO HIGH-YIELDING LOBLOLLY PINE PLANTATIONS[1/]

Edward Buckner, Richard Evans, John Mullins and Eyvind Thor[2/]

Abstract.--A split-plot design was used to test no treatment, fire plowing and double disking as main treatments for controlling residual hardwoods following a commercial timber harvest and planting 1-0 seedlings vs direct seeding as sub-plot treatments for converting a low-quality hardwood stand to a loblolly pine plantation. This evaluation was made at plantation age 23. Double disking was more effective than the other site preparation treatments and planting was more effective than direct seeding. Average annual growth where this combination was used was 2.4 cords per acre per year. Although less productive, the following treatment combinations resulted in stands of acceptable stocking: plow/plant, no site preparation/plant and disk/seed. High yields from the disked/planted plots makes this treatment attractive for intensive management. Planting without site preparation appears to be a viable option on small ownerships where intensive site preparation is not feasible.

## INTRODUCTION

The long-term and high risk nature of forestry investment is such that production-oriented foresters generally prefer to "practice their trade" on suitable land that is free from conflict with other possible land-use options (e.g., wilderness, agriculture, urban development, natural areas, etc.). Finding land free from these constraints that is suitable for the practice of intensive forestry is becoming increasingly difficult as pressures for land increase. "The Barrens," an extensive region on the Eastern Highland Rim in south-central Tennessee, may be one such area.

This flat to gently rolling region is covered with a loess mantel in which soils develop that commonly have a fragipan at 18-24 inches. The characteristic soil for this region is Dickson silt loam (undulating phase). It is not in demand for agricultural crops although there is increasing use for pasture. It is not suitable for subdivision development or other urban construction due to impermeability. Septic systems do not work efficiently, especially in the winter when a pearched water table commonly waterlogs the soils.

The "native" forests also suggest that these soils would be unproductive for forest crops. The dominant trees are primarily oaks - scarlet (Quercus coccinea L.), chestnut (Quercus prinus L.), post (Quercus stellata Wangenh.), blackjack (Quercus marilandica Muenchh.), and southern red (Quercus falcata Michx.) with a few hickories, elms and an occasional ash. Understory trees are largely dogwood, sourwood and redbud. In the spring rapid evapotranspiration quickly dries the shallow rooting zone making drought a common occurrence during much of the growing season. The pines native to Tennessee are not generally found in this region.

A history of frequent fires, grazing and high-grading have combined to mask the potential productivity of these sites for forest crops. The general lack of interest in forest management by landowners likely results from the low inherent value of the native species, their degraded condition (fire scars, limbiness, etc.) and a general lack of markets for unprocessed forest products. Converting these sites to pine has not been widely practiced as the region is outside the procurement zones for all but 2 or 3 pulp companies.

In 1960 approximately 860 acres in "The Barrens" was acquired as surplus government property by the University of Tennessee, essentially all of which supported a low-quality hardwood forest that was typical for this region. It was composed of two distinct age classes - a poorly stocked overstory dominated by oaks that were generally over 10-12 inches dbh and an understory of mixed hardwoods generally less than 10 years old. In the mid-1950's an effective forest fire control program was implemented in Tennessee which allowed the younger age class to become established.

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## THE STUDY

This study was established in the winter of 1961-62. It was prompted by the apparent low productivity of the "native" forest cover. An early indication of the greater productivity of loblolly pine on these soils was evident from plantations established on Arnold Engineering properties (a federal ownership) in the 1940's and 50's.

Study objectives were to evaluate:

1) mechanical site preparation methods for controlling the residual hardwood understory sufficient to establish a loblolly pine plantation,

2) planting vs seeding for establishing a loblolly pine plantation, and

3) the potential for loblolly pine on these seemingly unproductive sites.

## METHODS

All merchantable timber 12 inches dbh and larger on the 115 acre study area was removed in a commercial timber sale. The remaining overstory trees (3 inches dbh and larger) were injected using a mixture of 2,4-D and 2,4,5-T. There remained a hardwood understory that would compete with planted pines.

The experimental design was a split plot arrangement of 3 site preparation treatments in which 2 planting methods were tested (Table 1). There were 3 replications; however, one was largely destroyed by a wildfire in 1970.

Table 1.--Main and subplot treatments for the split plot experimental design.

Main treatments were (plot size = 1,000' x 500'):
1. Control = no treatment of understory hardwoods (a few were damaged/killed by the logging operation).
2. Fire plow = opening fire plow lanes on 8 foot intervals.
3. Double disking = uniform coverage of entire area using bog-type disk.

Sub-plot treatments were (plot size 500' x 500'):
1. Direct seeding of stratified loblolly pine seed. In the disked plots seeding was done with a cyclone seeder at the rate of one pound per acre. In the fire plow plots seeding was continuous along the bottom of the trench while in the control plots seeded spots were spaced as were the planted trees and at the rate of 1/2 pound per acre using a Panama seeder.
2. Planting 1-0 loblolly pine seedlings on a spacing that would give 1,000 trees per acre (approximately 8' x 5.5').

These main and sub-plot treatment combinations give the following treatments in the 5.75 acre sub-plots:
1. no site preparation + direct seeding (in spots using Panama seeder)
2. no site preparation + planting seedlings
3. fire plow + direct seeding (continuous along fire plow trench)
4. fire plow + planting seedlings
5. double disking + direct seeding (broadcast using Cyclone seeder)
6. double disking + planting seedlings

Site preparation and planting were done in the spring of 1962. Twenty five permanent sample plots were established in each treatment plot. The stand parameters used in this report were obtained in the fall and winter of 1984-85, following the 23rd growing season.

## RESULTS AND DISCUSSION

Main treatment (site preparation) effects indicate that double disking resulted in significantly greater stocking and basal areas than the other two treatments (Table 2). Plots receiving this treatment also had significantly greater tree heights than the control and greater cordwood volumes than the plowed plots. Plowing did not result in significant improvement over the controls for any of the measured parameters. These plots had the lowest stocking, which was likely due to competition from residual hardwoods and frost heaving (as planting was in the bottom of the furrow where water often stood during the winter months).

Table 2.--Stand density and growth parameters for the various treatment combinations.

| Treatment | Trees per Acre | DBH (in.) | Height (feet) | Basal Area (sq.ft.) | Cords per Acre |
|---|---|---|---|---|---|
| AVERAGES FOR INDIVIDUAL TREATMENTS | | | | | |
| SITE PREPARATION | | | | | |
| None | 351$^{a}$ | 7.49 | 55$^{a}$ | 113.5$^{a}$ | 33.5$^{ab}$ |
| Plowed | 304$^{a}$ | 8.00 | 57$^{ab}$ | 106.6$^{a}$ | 32.4$^{a}$ |
| Disked | 430$^{b}$ | 7.76 | 58$^{b}$ | 146.6$^{b}$ | 45.1$^{b}$ |
| PLANTING METHOD | | | | | |
| Seeded | 294$^{a}$ | 7.67 | 55$^{a}$ | 97.1$^{a}$ | 28.6$^{a}$ |
| Planted | 438$^{b}$ | 7.80 | 59$^{b}$ | 149.6$^{b}$ | 46.0$^{b}$ |
| AVERAGED FOR COMBINED TREATMENTS[b/] | | | | | |
| SITE PREPARATION/PLANTING METHOD | | | | | |
| Disk/plant | 465 | 8.17 | 61 | 174.2 | 56.0 |
| Plow/plant | 387 | 7.66 | 58 | 127.3 | 38.9 |
| None/plant | 452 | 7.64 | 57 | 148.1 | 44.1 |
| Disk/seed | 405 | 7.49 | 56 | 128.2 | 37.8 |
| Plow/seed | 221 | 8.34 | 56 | 85.9 | 25.9 |
| None/seed | 198 | 7.27 | 52 | 61.7 | 17.6 |

a/ Values in columns followed by the same letter are not significantly different at the .05 probability level according to Duncan's Multiple Range Test.

b/ Statistical analysis of the combined treatments was not appropriate due to a fire that destroyed portions of two replications.

All of the tree/stand parameters measured were higher in the planted plots than in those established by direct seeding (Table 2). The one-year growth advantage of planted seedlings likely made them better competitors against hardwoods and accounts for their larger size. Higher stocking in all planted plots was not the case at age 5 when the double disked/direct seeded plots had 2,471 trees per acre, the heaviest stocking in the study at that time (Thor and Huffman, 1969). While high mortality is expected with stand development in such overstocked stands, a contributing factor may have been the slow early growth of seeded pines relative to sprouting hardwoods.

Although not analyzed statistically, all of the tree/stand parameters measured except average

diameter were the highest in the disked/planted plots (Table 2). This indicates that the rapid development of fully stocked pine stands is strongly dependent on effective control of hardwoods and the growth advantage provided by 1-0 pine seedlings. While the high stand densities likely reduced diameter growth, only the plow/seeded plots had higher average diameters. These large diameters were likely due to the low stocking combined with some hardwood control. However, stocking in these plots was unsatisfactory.

All stand parameters were the lowest where direct seeding was done with no site preparation (Table 2). Not only were these plots understocked, but individual tree parameters (height/diameter) were the lowest. This likely reflects the growth advantage of the relatively undisturbed hardwood understory over the direct seeded pines resulting in slow pine growth and high mortality.

Stands with satisfactory stocking were obtained in all of the planted plots and in the direct seeded plot that was double disked. In planted plots tree height and diameter appeared to improve with increasing intensity of site preparation but did not appear to be related to pine stand density. This suggests that the growth of individual pines, although in "free-to-grow" positions, were strongly influenced by the residual hardwoods. Low stocking in the plow/plant plots resulted because frost heaving was especially damaging to pines planted in the plow furrow. While this resulted in the lowest basal areas and volumes in the planted plots, these stands are now fully stocked (Table 2).

For both planting methods average diameter and height were the lowest where there was no site preparation. Since these parameters did not appear to be influenced by pine stocking the slower growth is likely due to hardwood competition, which was especially apparent in the seeded plots.

Since height differences among treatments were small and even the smaller pines were of pulpwood size, there was a strong correlation between basal area and cubic volume (cords) per acre (Table 2). Considering direct seeding with no site preparation to be the minimum silviculture that might be applied in establishing pines on these sites after removal of the hardwood overstory, cubic volume gains achieved in this study from applying more intensive treatments were:

| | no site prep seeded | < | plowed seeded | < | disked seeded | < | plowed planted | < | no site prep planted | < | disked planted |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Percent Gain | | | 47 | | 115 | | 121 | | 151 | | 218 |

The significant gains achieved in this study through intensive site preparation and planting seedlings are consistent with experience in pine plantation management throughout the South. Controlling the aggressive hardwoods that compete with and constantly threaten to replace pines on essentially all sites in the South is essential if vigorous, fully-stocked pine plantations are to be maintained. The rapid early growth of pines established on a "regular" spacing, as is best accomplished by planting genetically improved stock suited to the planting site, greatly increases the likelihood of obtaining vigorous, fully-stocked plantations in which competing hardwoods do not seriously erode productivity.

A major finding in this study was the productivity of the loblolly pine plantations established on these seemingly unproductive sites (Figure 1).

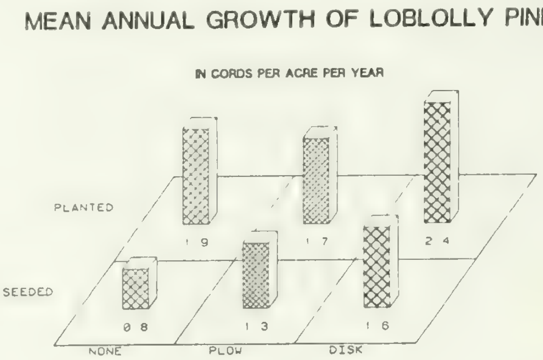


Figure 1. Average annual growth in cords per acre per year for 23 year old loblolly pine according to site preparation and planting methods.

Average annual growth of 2.4 cords/acre/year on a 23 year rotation represents high productivity even for the better pine sites in the South (Smalley and Bailey, 1974). That this occurred on "The Barrens" where pines do not normally grow and native hardwoods are largely inferior species of low quality, suggests that a significant improvement in forest productivity can be achieved by applying intensive forest practices that are now "standard" throughout much of the South. Although planting following commercial logging and injection of overstory trees without further site preparation established an acceptable plantation in this study, it is questionable whether this would be successful under present conditions. A long period of effective fire protection has resulted in larger, more vigorous hardwood stands. A similar treatment today would not likely be as effective as was the case in this study.

Additional research needed to further define the potential for pine on these sites includes studies on: 1) forest fertilization, 2) ripping (to fracture the fragipan), and 3) carrying the pine through a sawtimber rotation. A study to test thinning and prescribed burning as suitable treatments for maintaining stand vigor through a sawtimber rotation is being implemented on this study site.

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# RELATIONSHIPS BETWEEN HEIGHT GROWTH AND ROOT SYSTEM ORIENTATION IN PLANTED AND SEEDED LOBLOLLY AND SHORTLEAF PINES[1/]

Constance A. Harrington[2/], William C. Carlson[3/], and John C. Brissette[4/]

Abstract.--Trees in 34 young (3 to 8 year-old) loblolly (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.) stands in Arkansas, Oklahoma, and Texas were sampled to characterize the general root system orientation of planted and seeded trees. Seventeen stands had been planted, and 17 had been regenerated via artificial or natural seeding. In each stand, 12 trees were excavated and total height and height growth increments for the previous 3 years were recorded. Stand origin, either planted or seeded, influenced the percentage of trees in each of four general root system orientation classes. For both species, seeded trees were much more likely to have a single taproot type of root system than planted trees. For seeded and planted trees of both species, trees with root systems oriented downward (either with a main taproot or with several lateral roots) had better height growth than trees with surface-oriented root systems. The least favorable root orientation class differed by species; surface-oriented lateral root systems were least favorable for shortleaf pine, and taproots not oriented downward were least favorable for loblolly pine. Overall, 3-year height growth did not differ between seeded and planted trees; however, planting did increase the percentage of trees in the root orientation classes which were less favorable for height growth.

## INTRODUCTION

Loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pine are the major commercial tree species in Arkansas, southeastern Oklahoma and northeastern Texas. The natural range of shortleaf pine extends farther west and north than that of loblolly pine (Fowells 1965); however, in central Arkansas and southeastern Oklahoma large-scale plantings of loblolly pine outside of its natural range have been very successful (Lambeth and others 1984). In many areas, when natural stands of shortleaf pine are harvested, the site is regenerated by planting loblolly pine because of the greater growth rates that can be achieved over short rotations by loblolly on some sites.

In addition to inherent differences in growth rates between loblolly and shortleaf pines, other reasons for differential performance in plantations include differences in the quality of planting stock produced by nurseries and differences in the way the root systems of each species develop after planting. This study was designed to investigate if: (1) there were species differences in root system orientation between planted and seeded trees, and (2) differences in root system orientation were associated with differences in height growth. The information presented here is part of a larger study comparing root systems of planted and seeded loblolly and shortleaf pines.

## METHODS

Seventeen paired plots (34 plots in total) were set up in 3- to 8-year-old, well-established stands of either loblolly or shortleaf pine in Arkansas, Oklahoma, and Texas (fig. 1). One plot of each pair had been regenerated by artificial or natural seeding; the other had been planted using a local seed source. Both plots of each

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Figure 1. Location of sites used in root system orientation study: X= loblolly pine site, O= shortleaf pine site.

plot pair were of the same tree species, on similar soil with comparable site conditions and located within 10 km of each other; mean ages differed by a maximum of 2 years. Plots were established in both the Interior Highland and Upper Coastal Plain physiographic provinces. As would be expected given the overall range in site conditions and tree age, mean tree size varied substantially (table 1).

Randomly generated X-Y coordinates were used to locate 12 sampling points in each plot; the tallest of the five trees closest to the sampling point was chosen as a sample tree if it appeared healthy, free from major damage, and had one main terminal leader. If the tallest tree did not meet the criteria, another tree was substituted. Trees with minimal top damage were selected; however, on some sites almost all trees exhibited repeated replacement of the main terminal. The observed damage was probably caused by Nantucket pine tip moth (Rhyacionia frustrana).

Each sample tree was tagged on the north side and marked to indicate location of the groundline. Trees were then excavated using shovels and mattocks to a depth of approximately 40 cm. Lateral roots were severed about 20 cm out from the base of the tree. Total height and height increment for the three growing seasons prior to excavation were measured for each tree. Height increments were determined by counting the number of height growth flushes and using characteristics such as relative needle length, relative flush length, needle retention, and changes in bark and branching characteristics. Questionable flushes were assigned to the correct year by cutting above and below the bud scale scars and counting the number of annual rings. After the height measurements were taken the tops of the trees were severed from the roots 15 to 25 cm above the groundline mark.

Root systems were transported to the laboratory, washed, and then either measured immediately or stored indoors until measured. Prior to measurement, stored root systems were rehydrated by soaking in water for 24 to 48 hours. Roots were suspended in a cylindrical frame for measuring; the groundline mark was placed at the top of the frame. The frame was 36 cm deep and divided into three 12-cm deep layers. Each layer was subdivided into 4 compass quadrants; thus, the frame had 12 measurement sections plus a top and a bottom. Tree diameter was measured at the groundline mark.

Root systems were classified as to their general orientation (fig. 2). Orientation 1 was a root system with one major root oriented downward. No attempt was made to distinguish between undisturbed taproots and a major root that may have originated after the original root was cut or damaged. Orientation 1 also included taproots with major turns if the overall orientation of the root system was primarily downward; thus this category would have included both trees with straight (vertical) taproots and trees with a taproot originally in a "L" or "J" configuration that recovered or corrected itself and grew downward. Orientation 2 was for root systems having one major root, but the root system was not oriented downward; this included root systems having an "L" or "J" configuration that were not included in orientation 1. Orientation 3 was applied to root systems that had a downward orientation but more than one major root was involved. This included root systems with two to four large "sinker" roots as well as more fibrous root systems with a strong downward orientation. Orientation 4 was for root systems without a major root where the orientation of the lateral roots was primarily outward rather than downward.

The number of major turns made by the taproot between groundline and where the taproot ended or where it exited the measuring frame was recorded for all roots. After the root systems were measured the stump was severed from the root system at the groundline mark and aged by counting the number of annual rings.

Planted and seeded trees were compared by root orientation class using a chi-square test for each species-physiographic province

Table 1.--Mean tree characteristics by species, physiographic province and stand origin.

| Species | Physiographic province | Stand origin | Number of plots | Age | Total height | Diameter at groundline |
|---|---|---|---|---|---|---|
| | | | | years | m | cm |
| Shortleaf pine | Interior Highlands | Seeded | 5 | 4.4 | 1.5 | 3.5 |
| | | | | (0.4)[1/] | (0.3) | (0.6) |
| | | Planted | 5 | 4.1 | 1.4 | 3.5 |
| | Coastal Plain | Seeded | 4 | 6.5 | 4.2 | 8.3 |
| | | | | (1.0) | (1.0) | (1.6) |
| | | Planted | 4 | 5.7 | 3.8 | 8.3 |
| Loblolly pine | Interior Highlands | Seeded | 4 | 4.8 | 2.1 | 5.8 |
| | | | | (0.4) | (0.1) | (0.4) |
| | | Planted | 4 | 5.3 | 2.2 | 6.2 |
| | Coastal Plain | Seeded | 4 | 7.1 | 5.3 | 10.0 |
| | | | | (1.1) | (1.1) | (1.7) |
| | | Planted | 4 | 6.1 | 4.3 | 10.3 |

1/ Value in parentheses is the mean absolute difference between seeded and planted paired plots.

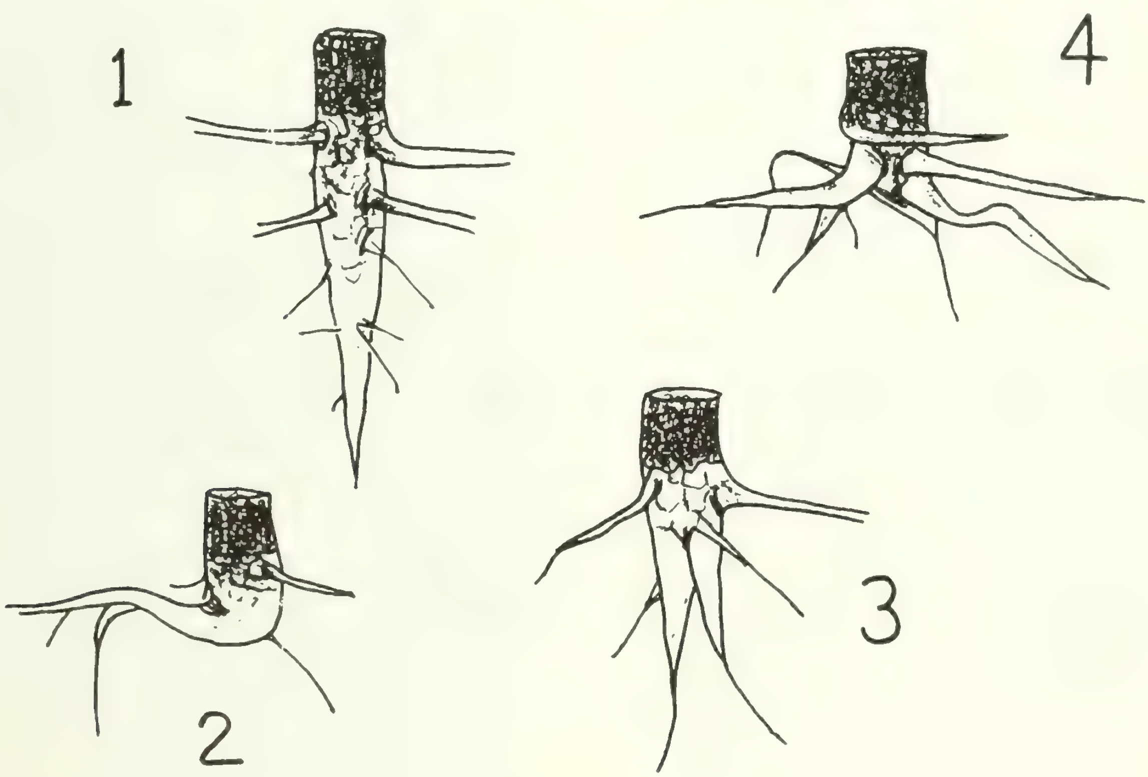


Figure 2. The four root system orientation classes. See text for detailed explanation.

group. Differences between planted and seeded trees in annual and 3-year total height growth were tested on a paired-plot basis and by combining trees in each species-physiographic province group. The effects of root orientation class on height growth were examined by: (1) comparing weighted averages for height growth by root class for each species-province combination, and (2) ranking root orientation classes in each plot by height growth in the year preceding excavation. A split-plot analysis of variance was precluded by the number of empty cells. Loblolly and shortleaf pine plots had not been paired in site selection. Thus statistical tests of the differences between species were not appropriate and direct comparisons between species could not be made.

## RESULTS AND DISCUSSION

### Root orientations

The majority of seeded loblolly and shortleaf pines had a taproot type of root system (root orientation class 1; table 2). There were small but consistent differences between provinces and between species in the percentage of seeded trees having taproots; these differences could be the result of variability in plant populations or could be related to the generally higher rock and gravel content in the Interior Highlands compared to the Coastal Plain. In addition, shortleaf pine plots in the Interior Highlands had higher rock contents than the loblolly pine plots. For both species in both provinces, the distribution of root systems by root orientation class differed between planted and seeded trees. The percentage of trees in orientation 1 was lower in planted than in seeded stands, and, in general, the percentage of trees in the other three root classes was higher in planted stands.

Planted trees of both species were more likely to have one major root (orientation classes 1 and 2) in the Coastal Plain than in the Interior Highlands. The reasons for this difference between physiographic provinces are not known. Growing conditions on the Coastal Plain sites were generally more favorable and this may have encouraged the retention of a taproot type of root structure. Root systems with two or more major laterals heading downward (classified as orientation class 3) could have "grown into" orientation class 1 if one of the downward-oriented laterals increased in relative size and appeared dominant or if two or more roots twisted together, were overgrown, and appeared as one root. This type of scenario is more likely to have occurred in the Coastal Plain than in the Interior Highlands because the root systems in the Coastal Plain were more developed due to their somewhat greater age and better growing conditions.

### Height growth

As would be expected in these young stands, annual height growth is still increasing over time (table 3). Differences in 3-year and annual height growth between planted and seeded trees were generally small and inconsistent. None of the paired-plot analyses of the total 3-year height growth resulted in statistically significant ($p=0.10$) differences between planted and seeded trees for either loblolly or shortleaf pine. Analysis of height growth by the three individual years also resulted in nonsignificant differences between planted and seeded plots for shortleaf pine in both provinces.

The seeded loblolly pine plots in the Coastal Plain had significantly greater annual height growth the 3rd year prior to excavation ($n-3$) than planted trees; however, this difference in growth between stand origins was not maintained over time.

The loblolly pine plots in the Interior Highlands exhibited a different pattern of height growth for seeded and planted stand origin types. For these plots, seeded stands had significantly less annual growth than planted stands the 3rd year prior to excavation ($n-3$), the same growth the 2nd year prior to excavation ($n-2$), and greater annual growth the year prior to excavation ($n-1$). This group of loblolly pine plots was more similar in stand history than the other species-province groups, and this greater similarity may have allowed small differences in height growth patterns to be visible. All the loblolly pine plots in the Interior Highlands had been either planted or seeded after the regeneration failure associated with a severe drought in 1980. Thus, although the stands had been established the same year, the seeded stands were a year younger (age from seed) than the planted stands, and initially had poorer growth. Once the seeded trees became well established, however, they were able to catch-up to the planted trees. The fact that the seeded trees were able to catch-up with the planted trees indicates that there may have been detrimental effects associated with the plantings.

### Height growth by root orientation class

The patterns of height growth by root orientation class differed between species but were generally similar for planted and seeded trees and across provinces (table 4). For both planted and seeded shortleaf pine in the Interior Highlands, orientation class 4 had the poorest mean height growth; there was very little difference in mean growth between the other three root classes. Planted shortleaf pine in the Coastal Plain followed the same pattern--with the poorest mean height growth associated with orientation class 4. Seeded shortleaf pine in the Coastal Plain exhibited a different pattern, with the best growth in orientation root class 4 and the worst in orientation class 2. This anomaly was based on a few trees, however, and is probably the result of sampling variability.

Table 2.--Distribution of root systems by root orientation class, stand origin, physiographic province and species.[1/]

| Species | Physiographic province | Stand origin | Number (and percent) of root systems by root orientation class 1 | 2 | 3 | 4 | $X^2$ | p level |
|---|---|---|---|---|---|---|---|---|
| Shortleaf pine | Interior Highlands | Seeded | 38(63) | 2(3) | 13(22) | 7(12) | 9.81 | 0.025 |
| | | Planted | 21(35) | 5(8) | 22(37) | 12(20) | | |
| | Coastal Plain | Seeded | 35(73) | 2(4) | 7(15) | 4 (8) | 6.15 | 0.150 |
| | | Planted | 25(52) | 8(17) | 8(17) | 7(15) | | |
| | All Plots | Seeded | 73(68) | 4(4) | 20(18) | 11(10) | 15.02 | 0.005 |
| | | Planted | 46(43) | 13(12) | 30(28) | 19(18) | | |
| Loblolly pine | Interior Highlands | Seeded | 37(77) | 3(6) | 5(10) | 3 (6) | 24.22 | 0.005 |
| | | Planted | 14(29) | 3(6) | 23(48) | 8(17) | | |
| | Coastal Plain | Seeded | 39(81) | 1(2) | 6(12) | 2 (4) | 14.02 | 0.005 |
| | | Planted | 22(46) | 7(15) | 12(25) | 7(15) | | |
| | All Plots | Seeded | 76(79) | 4(4) | 11(12) | 5 (5) | 34.38 | 0.005 |
| | | Planted | 36(38) | 10(10) | 35(36) | 15(16) | | |

[1/] The hypothesis that planted and seeded trees did not differ in their distribution across root orientation classes was tested using chi-square ( $X^2$ ).

Table 3.--Mean height growth by year prior to excavation, stand origin, physiographic province and species.

| Species | Physiographic province | Stand origin | Mean height growth by year[1/] n-3 | n-2 | n-1 | 3-yr total |
|---|---|---|---|---|---|---|
| | | | cm | | | |
| Shortleaf pine | Interior Highlands | Seeded | 31 | 42 | 52 | 125 |
| | | Planted | 28 | 42 | 62 | 132 |
| | Coastal Plain | Seeded | 76 | 76 | 100 | 252 |
| | | Planted | 71 | 83 | 106 | 260 |
| Loblolly pine | Interior Highlands | Seeded | 40**[2/] | 58 | 88** | 186 |
| | | Planted | 48 | 56 | 76 | 181 |
| | Coastal Plain | Seeded | 92** | 92 | 115 | 299 |
| | | Planted | 80 | 98 | 121 | 299 |

[1/] n-3 = 3 years prior to excavation, n-2 = 2 years ...

[2/] Significance of differences in growth between planted and seeded trees in a species-physiographic province group is indicated by the symbol next to value for seeded trees, **p<0.01.

Table 4.--Mean height growth the year prior to excavation by root orientation class, stand origin, physiographic province, and species.

| Species | Physiographic province | Stand origin | Height growth by root orientation class[1/] 1 | 2 | 3 | 4 | All classes |
|---|---|---|---|---|---|---|---|
| | | | - - - - - - | - - - - | cm | - - - - | - - - - - - |
| Shortleaf pine | Interior Highlands | Seeded | 53 | 52 | 53 | 43 | 52 |
| | | Planted | 66 | 68 | 64 | 47 | 62 |
| | Coastal Plain | Seeded | 95 | 90 | 119 | 122 | 100 |
| | | Planted | 109 | 98 | 118 | 91 | 105 |
| Loblolly pine | Interior Highlands | Seeded | 90 | 66 | 88 | 86 | 88 |
| | | Planted | 70 | 58 | 83 | 76 | 76 |
| | Coastal Plain | Seeded | 114 | 89 | 136 | 100 | 115 |
| | | Planted | 127 | 103 | 124 | 114 | 121 |

1/ Refer to Table 2 for the number of roots in each class.

Table 4 combines information from trees in each species-province combination; differences between values on each line of the table could be due to plot effects as well as the effects of root orientation class. The plot effects were eliminated by examining the effects of root system orientation on height growth on a plot-by-plot basis. For each plot the root orientation class having the best height growth was determined (table 5). For shortleaf pine, downward-oriented classes (orientation 1 and 3) had the greatest number of plots with the best height growth. Orientation class 4 did not have the best height growth in any of the shortleaf pine plots sampled. Loblolly pine exhibited a similar pattern with the downward-oriented classes (1 and 3) most frequently having the best height growth per plot. Orientation class 2 was apparently the least favorable class for loblolly pine, as no plots were tallied in this class.

## GENERAL DISCUSSION AND CONCLUSIONS

Root system structure or general orientation can affect tree performance in several categories: initial survival, initial and later growth, stability (e.g., resistance to windthrow or snow and ice damage), and response to silvicultural treatments (e.g., soil-active herbicides). Our study was based on healthy trees in well-established stands. Thus nothing can be concluded about the effects of root orientation on survival or stability.

Loblolly pine, on the other hand, had the poorest height growth in orientation class 2; this pattern was consistent for planted and seeded trees in both provinces (table 4). In general, loblolly pines in orientation class 1 had mean height growth approximately equal to or better than the average for all orientation classes. Planted loblolly in the Interior Highlands were an exception. Examination of the data on the number of major turns made by the tap or main root revealed a possible reason for this discrepancy. If loblolly pine seedlings are sensitive to root deformation as may be indicated by the poorer growth associated with orientation class 2, then poorer growth should also be associated with trees in orientation class 1 that had major turns. Planted loblolly pines in orientation class 1 in the Interior Highlands had an average of 2.7 major turns per tree, while seeded trees averaged less then 0.5 turns per tree. No major turns were recorded for either planted or seeded loblolly pine in orientation class 1 in the Coastal Plain. Coastal Plain trees may have had fewer turns recorded because the sampled soils had fewer restrictions to rooting (and would have been easier to plant in). In addition, the root systems of young trees are very plastic and can quickly grow over bends or twists that do not result in large displacements from the center of the main root. Thus the generally older and larger trees on the Coastal Plain have put on a thicker sheath of wood than those in the Interior Highlands and may have "hidden" or grown over any major turns that were associated with stand establishment.

Table 5.--Distribution of the maximum mean height growth per plot (Max H) the year prior to excavation by root orientation class.

| Species | Physiographic province | Stand origin | Max H by root class[1/] 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| | | | - - - number of plots - - - - | | | |
| Shortleaf pine | Interior Highlands | Seeded | 3 | 0 | 2 | 0 |
| | | Planted | 2 | 1 | 2 | 0 |
| | Coastal Plain | Seeded | 1[2/] | 1 | 2 | 0 |
| | | Planted | 1 | 1 | 2 | 0 |
| Total all plots | | | 7 | 3 | 8 | 0 |
| Loblolly pine | Interior Highlands | Seeded | 2 | 0 | 2 | 0 |
| | | Planted | 1 | 0 | 2 | 1 |
| | Coastal Plain | Seeded | 2 | 0 | 2 | 0 |
| | | Planted | 2 | 0 | 1 | 1 |
| Total all plots | | | 7 | 0 | 7 | 2 |

1/ Root orientation classes with only one value per plot were excluded from consideration

2/ All root systems in this plot classified as root orientation class 1.

Differences were observed between seeded and planted populations in the percentage of trees in the four root system orientation classes. In particular, planted trees were much less likely to have one main downward oriented taproot than seeded trees. When all trees were combined, there were no significant differences in 3-year height growth between planted and seeded trees. However, there were some differences in height growth between root orientation classes, and planting increased the percentage of the population in the less desirable root orientation classes. Height growth was best in the root classes with downward-oriented root systems. The effect of root deformation or root orientation in relation to height growth differed somewhat by species. In particular, loblolly pines performed poorest in root orientation class 2, and shortleaf pines performed poorest in root orientation class 4.

The results of previously published studies on the effects of root orientation or deformation on future growth have not been consistent. Hay and Woods (1974) reported that larger loblolly pines had more root deformation than smaller seedlings and speculated that root deformation may stimulate growth. They also commmented that the larger seedlings (with more root deformation) had more surface roots, which may initially be beneficial in taking advantage of summer showers. Hay and Woods (1974) mentioned the possibility that the largest seedlings at the time of planting may have been more likely to have been J-rooted than smaller seedlings. This alternative hypothesis was confirmed by field studies reported by Mexal (and others) 1978. Therefore it seems quite possible that the largest seedlings initially grew the best, in spite of root deformation.

In another study, loblolly pine seedlings were planted with purposely deformed roots (Cabrera and Woods 1975). They reported no statistical differences in height between treatments at age 3. It is noteworthy, however, that photographs of root system structure showed less variation than encountered in the present study, and that the ranking of growth by treatment showed better growth in the treatments with the least deformation. Another reason for the differences in results between the Cabrera and Woods study in 1975 and this study is the definition of the root orientation (or deformation classes). We compared height growth based on root system orientation at the end of the height-growth period, while they used root system characteristics at the time of planting.

For example, our root orientation class 2 included only root systems with uncorrected J or L configurations, while their roots with J or L configurations could include both root systems that remained as J or L and root systems that corrected themselves.

Root system deformation and general root system orientation are factors in the long-term performance of both loblolly and shortleaf pine plantations. Foresters should maintain tight controls over the quality of the planting to ensure that expected growth rates are achieved. Careful writing of planting contracts with penalties for nonperformance and on-the-job inspections should result in more uniform and better growing plantations. In addition, utilization of site preparation treatments such as ripping, which make it easier to correctly plant trees, should also result in less root system deformation and better seedling performance.

## ACKNOWLEDGEMENTS

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# NURSERY CULTURAL PRACTICES, SEEDLING MORPHOLOGY, AND FIELD PERFORMANCE OF LONGLEAF PINE[1]

Glyndon E. Hatchell[2]

Abstract.--Preliminary results of a nursery and outplanting study of longleaf pine indicate that nursery cultural practices and certain morphological attributes of 1-0 bare-root seedlings strongly affected early field performance on a sandhills site. Seedbed density and lateral-root pruning altered morphological attributes of stock. Lateral-root pruning, which was associated with increased abundance of fibrous roots and ectomycorrhizae, significantly improved survival during droughty conditions in the spring and summer of the first growing season. Seedling vigor and survival were strongly correlated with abundance of fibrous roots and ectomycorrhizae, the number of large first-order lateral roots, and the interaction of these attributes.

## INTRODUCTION

Morphological and physiological characteristics of planting stock and genetic factors influence the quality of southern pine seedlings (Brissette 1984). The ultimate measure of seedling quality is generally considered to be field performance.

Results of nursery and outplanting studies of longleaf pine (*Pinus palustris* Mill.) indicate that inoculation of fumigated nursery soil with *Pisolithus tinctorius* (Pt) during spring sowing and certain nursery cultural practices greatly increase survival and early growth of seedlings planted on deep sandy soils (Hatchell 1985). In addition to inoculation, nursery cultural practices that increase development of fibrous roots, such as optimum seedbed density, lateral-root pruning, maintenance of optimum nutrient availability, and adequate growing space between individual seedlings, also tend to increase seedling quality. This research showed that seedlings with abundant fibrous roots and abundant ectomycorrhizae survived and grew better than seedlings with smaller and fewer fibrous roots supporting few ectomycorrhizae.

This paper summarizes preliminary results of a longleaf pine study testing seedling responses in the nursery and in the field. The objectives of this study were (1) to test the effects of nursery cultural practices on morphological attributes of bare-root seedlings and on field performance after outplanting on a sandhills site, and (2) to associate key morphological attributes of the seedlings with field performance for a better understanding of seedling quality and for possible use as a guide for culling poor quality seedlings.

## NURSERY EXPERIMENT

### Methods

Seedling production.--Seedlings were produced in 1985 at the Whitehall Experimental Nursery, Athens, Georgia. Aboveground nursery beds containing a uniform mixture of forest topsoil, sand, and milled pine bark (2:1:1, volume ratio) were fumigated with methyl bromide under clear plastic. Soil samples collected after fumigation were analyzed and, in ppm, the average nutrient contents of the soil were: total N = 460, available P = 38, and extractable K, Ca, and Mg = 74, 220, and 19, respectively; pH was 4.7 and organic matter content was 1.2% (Analyses by A&L Laboratories, Inc., Memphis, Tennessee). These relatively high nutrient contents were from residual fertilizer concentrations applied in production of longleaf pine in previous years. Fertilizer (10-10-10) was broadcast at 500 lb/acre. Vegetative inoculum of Pt, with a moisture content of 72 percent and pH 5.11 was mixed with the upper 4 inches of soil before sowing at the rate of 75 $ml/ft^2$ of soil surface. Longleaf pine seed (Dodge County, Georgia, seed source) were sown on March 20, 1985, at two times the desired seedbed density, and nursery beds were thinned May 20, 1985, to the seedling density that was assigned to each plot.

The nursery phase of this study was a 2x2x2 factorial experiment replicated in four randomized complete blocks. The factors and levels consisted of two seedbed densities (6 or 12 $seedlings/ft^2$), two spacings of seed drills (6 or 12 inches), and two lateral-root pruning treatments (pruned or unpruned). Offset "double" drills were sown at the 12-inch spacing to provide additional growing space between seedlings. Lateral roots were pruned on June 25, August 16, and September 30, 1985, by vertically cutting roots midway between seed drills to a depth of 6 inches.

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Seedlings were side dressed on June 24, July 15, August 13, and September 3, 1985, with ammonium nitrate at the rate of 50 lb/acre N and with muriate of potash at the rate of 10 lb/acre K. Captan was applied as a drench to the soil in all beds at 4.2 lb/acre on March 26, 1985. Benlate was applied as a drench at the recommended rate from July to October to control *Rhizoctonia* needle blight.

Lifting and evaluating stock.--Seedlings were lifted and seven morphological attributes of each seedling were assessed on December 9 to 12, 1985. All seedlings from the border rows of all plots were excluded from this assessment. Fifty healthy and undamaged seedlings with >3/16 inch root-collar diameter (RCD) and having other specifications of plantable stock suggested by Wakeley (1954) were randomly selected from each of the 32 plots in the nursery experiment for outplanting.

Seedlings that did not meet specifications of Wakeley's (1954) grade 1 or 2, had mechanical damage or had fusiform rust (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiform*) galls, were rated as culls. Cull rate by treatment is shown in Table 1. The mean cull percentage was 10.1 and 13.2 for seedbed densities of 6 and 12 seedlings/ft$^2$, respectively. The higher cull percentage in the highest bed density was caused by a greater proportion of seedlings with less than 3/16 inch RCD. However, fusiform rust cankers caused more culls at either seedbed density than did the failure of seedlings to meet morphological standards.

The seven morphological attributes included (1) RCD, (2) total fresh weight, (3) length of needles, (4) number of large first-order lateral roots (diameter >1 mm), (5) arbitrary rating of the abundance of fibrous roots as low, medium, or high, (6) percent of short roots ectomycorrhizal with Pt, and (7) percent of short roots ectomycorrhizal with all fungi. Taproots were cut to a uniform length of 10 inches on all seedlings. Numbers of first-order lateral roots larger than 1 mm were included as parameters following the recommendation of Kormanik (1986).

Data analysis.--The main effects and interactions of the three nursery cultural treatments on the morphological attributes of seedlings were examined by analysis of variance (ANOVA). Linear correlations among the morphological attributes were computed.

## RESULTS AND DISCUSSION

Effects of nursery cultural practices.--Seedbed density had a highly significant effect on six of the seven morphological attributes that were assessed. Needle length, which averaged 18 inches for all treatments, was the only measured attribute not affected by the nursery cultural treatments. Seedlings produced at the 6/ft$^2$ seedbed density had 25 percent larger RCD, 56 percent greater fresh weight, and nearly twice as many large first-order lateral roots as seedlings produced at the 12/ft$^2$ density. However, a greater abundance of fibrous roots and a higher percentage of short roots ectomycorrhizal with Pt or all fungi occurred on seedlings produced at the higher seedbed density (table 2). Lateral-root pruning caused an increase in the abundance of fibrous roots.

Relationships among morphological attributes. --Linear correlation coefficients among six morphological attributes (excluding needle length) of the 1,600 seedlings that were assessed are shown in Table 3. Total fresh weight was strongly correlated with RCD (r = +0.82). The number of large first-order lateral roots was positively correlated with total fresh weight and RCD, with values of +0.79 and +0.77, respectively. The abundance of fibrous roots was positively correlated with the percent of short roots ectomycorrhizal with either Pt or all fungi (r = +0.59 and +0.61, respectively). The percent of short roots ectomycorrhizal with Pt was positively correlated with the percent of short roots ectomycorrhizal with all fungi (r = +0.99). The abundance of fibrous roots was negatively related to the number of large first-order lateral roots, but the r value was only -0.16.

Table 4 shows the frequency distribution by number of lateral roots for the 1,600 seedlings in the test, with percentage of seedlings having various combinations of fibrous-root abundance. For example, seedlings with low abundance of fibrous roots coupled with 0-2, 3-5, and 6-8 larger first-order laterals were 2.69, 6.12, and 7.69 percent, respectively, or a total of 16.5 percent of all the seedlings in the test. Only 9 percent of the seedlings in all fibrous root classes had 15 or more large lateral roots. The distribution of seedlings by classes of fibrous roots was 29 percent with low, 56 percent with medium, and 15 percent with high abundance.

## FIELD EXPERIMENT

### Methods

Study area.--The outplanting site was on the Savannah River Forest Station, Aiken, South Carolina. The soil is Lakeland sand. The study area was within a larger unit designated for site preparation using the "brown and burn" method, because it was occupied principally by scrub oaks and other unmerchantable hardwoods and shrubs. The herbicide Pronone 10-G was applied at 13 lb/acre during May 1985, and the site was burned in September 1985. The cost of site preparation, \$48/acre for herbicides and \$10 to \$20/acre for burning, was much less than an alternate method, V-blading and rootraking, with expected costs of \$170/acre.

Plantable seedlings were assigned numbers indicating their nursery treatment, tagged, packed in wet peat moss, sealed in shipping bags, and placed in cold storage for 10 days or less until removal for planting. Seedlings were machine-planted on December 17, 1985, at approximately 6x10 foot spacing.

Experimental design.--Seedlings were planted completely at random in 18 rows without regard to

nursery cultural treatment. Treated stakes with tags were placed beside the 1st, 20th, 40th, etc., and last seedling on each row. A record was made of the seedling number (1-1,600) corresponding to each planting position and row number.

Seedling inventory.--Survival and vigor were recorded during September of the first growing season. Vigor of surviving seedlings was judged on a scale of 1 to 5 as follows: 1 = very poor, perhaps dying; 2 = poor; 3 = average; 4 = good; 5 = excellent, with total height $\geq$ 4 inches.

Data analysis.--ANOVA's were made of the main effects and interactions of nursery cultural treatments on survival and vigor in September of first year. Linear correlation coefficients between survival and vigor as dependent variables and morphological attributes as independent variables were computed, and the strongest relationships were tested by multiple regression analysis.

## RESULTS AND DISCUSSION

Spring and early summer of 1986 during the first growing season were extremely dry, with a rainfall deficit of approximately 10 inches by the end of July. Also, the average daily temperature during July was the highest recorded in this locality during the past 100 years. Thus, it is remarkable that an overall mean survival of 61.4 percent was recorded in September 1986 near the end of the first growing season.

Effects of nursery cultural practices on field responses.--Both lateral-root pruning and seedbed density significantly affected vigor of seedlings, but lateral-root pruning was the only nursery cultural treatment that significantly affected survival. Mean survival was 71.6 and 51.2 percent for pruned and unpruned seedlings, respectively (table 5). Mean vigor ratings were also higher for pruned seedlings than unpruned seedlings, and seedlings produced at the 6/ft$^2$ seedbed density had higher vigor than seedlings produced at the 12/ft$^2$ density.

Relation of field responses to morphological attributes.--Linear correlations between field responses and certain morphological attributes of bare-root stock are shown in Table 6. Significant positive correlations were found between survival and the following attributes: rating of the abundance of fibrous roots; percent of short roots ectomycorrhizal with Pt; percent of short roots ectomycorrhizal with all fungi; and the interaction term (rating of the abundance of fibrous roots) x (number of large first-order lateral roots). Significant positive correlations were found between seedling vigor and the following attributes: RCD; total fresh weight; number of large first-order lateral roots; the interaction term (RCD) x (number of large first-order lateral roots); and the interaction term (rating of the abundance of fibrous roots) x (number of large first-order lateral roots).

Multiple linear regressions with three independent variables, rating of the abundance of fibrous roots, number of large first-order lateral roots, and (rating of the abundance of fibrous roots) x (number of large first-order lateral roots) had an $R^2$ value of 0.401 with survival as dependent variable and an $R^2$ value of 0.583 with vigor as dependent variable. Both of these regressions were highly significant.

Survival and vigor were computed by class of fibrous-root abundance and number of large first-order lateral roots (table 7). Survival was 82 percent or more for planting stock having a high abundance of fibrous roots coupled with six or more large first-order lateral roots, and the vigor rating for this group of seedlings was above average. In contrast, survival was 38 percent or less for stock having a low abundance of fibrous roots coupled with eight or less large first-order lateral roots and the vigor rating for seedlings with these attributes was below average.

Culling seedlings with certain attributes to improve field performance.--Only seedlings that did not meet the specifications for Wakeley's grades 1 and 2 were culled. If higher standards for selecting planting stock had been used, field performance might have been improved. If seedlings with low abundance of fibrous roots and <9 large first-order lateral roots had been culled, the resulting cull percentages would have been 10.5 for seedlings receiving lateral-root pruning and 22.5 for unpruned seedlings. After such culling, the expected survival would have been 75.0 percent for pruned seedlings and 57.6 percent for unpruned seedlings. After subtracting mean survival for the respective treatments (71.6 percent for pruned and 51.2 percent for unpruned, table 5) one obtains the following increase in survival due to such culling: 3.4 percentage points for the lateral-root pruning treatment and 6.4 percentage points for the unpruned treatment, based on the actual performance of seedlings.

## CONCLUSIONS

Although these results and findings are preliminary, they indicate that nursery cultural practices for longleaf pine, especially lateral-root pruning and seedbed density, strongly influence field performance. Responses to treatments in the field reflected changes in key morphological attributes. These include the relative abundance of fibrous roots, the number of large first-order lateral roots, and their interaction. First-year survival and vigor were more closely correlated with these attributes than with other seedling characteristics. When high-quality seedlings are produced under sound nursery managment practices, including fumigating soil, inoculating with Pt, controlling seedbed density with a range of 6 to 12 seedlings/ft$^2$, pruning lateral roots two or three times during the growing season, fertilizing at near optimum levels throughout the growing season, and controlling pests, then one can expect only a modest increase in survival by culling seedlings with undesirable morphological attributes. However, important gains in field performance are directly attributable to improvement in seedling quality by certain nursery

cultural practices and the resulting alterations in key morphological attributes.

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Table 1.--Cull percentage for 1-0 longleaf pine seedlings based on Wakeley's (1954) minimum specifications for longleaf pine grade 2 stock, by nursery cultural treatment

| Seedbed density, spacing between seed drills, and lateral root pruning treatment | Primary reason for culling: Fusiform canker | Root-collar diameter <3/16 inch | Damaged root system | Total culls |
|---|---|---|---|---|
| | Cull percentage | | | |
| 6 seedlings/$ft^2$ | | | | |
| 6-inch drills-pruned | 7.5 | 0.9 | 2.7 | 11.1 |
| 6-inch drills-unpruned | 6.9 | 0.9 | 0.9 | 8.7 |
| 12-inch drills-pruned | 5.9 | 1.4 | 2.2 | 9.5 |
| 12-inch drills-unpruned | 4.9 | 2.2 | 4.0 | 11.1 |
| Mean | 6.3 | 1.3 | 2.5 | 10.1 |
| 12 seedlings/$ft^2$ | | | | |
| 6-inch drills-pruned | 6.6 | 4.9 | 0.0 | 11.5 |
| 6-inch drills-unpruned | 7.5 | 3.9 | 0.9 | 12.3 |
| 12-inch drills-pruned | 5.6 | 7.3 | 0.9 | 13.8 |
| 12-inch drills-unpruned | 7.6 | 7.6 | 0.4 | 15.6 |
| Mean | 6.8 | 5.9 | 0.5 | 13.2 |

Table 2.--Means of morphological attributes of longleaf pine bare-root stock by nursery cultural treatment

| Treatment and level | Root-collar diameter | Total fresh weight | No. 1st-order laterals | Fibrous root rating | % of Short roots ectomycorrhizal with: Pt | All fungi |
|---|---|---|---|---|---|---|
| | Inch | Gram | Number | Scale:1 to 3 | - - Percent - - | |
| Lateral-root pruning: | | | | | | |
| Pruned | 0.45 | 87 | 7.1 | 2.0 | 60 | 67 |
| Unpruned | 0.45 | 90 | 7.3 | 1.7 | 56 | 63 |
| Seedbed density: | | | | | | |
| 6/$ft^2$ | 0.50 | 108 | 9.3 | 1.7 | 54 | 61 |
| 12/$ft^2$ | 0.40 | 69 | 5.1 | 2.0 | 62 | 69 |
| Drill spacing: | | | | | | |
| 6 inches | 0.44 | 86 | 7.0 | 1.9 | 58 | 64 |
| 12 inches | 0.45 | 90 | 7.4 | 1.9 | 59 | 66 |

Table 3.--Linear correlation coefficients among morphological attributes of 1-0 longleaf pine seedlings

| | Root-collar diameter | Total fresh weight | No. 1st-order laterals | Rating fibrous roots | % Short roots w/ Pt ecto[1] | % Short roots w/ all ecto[2] |
|---|---|---|---|---|---|---|
| | | r value and significance level[3] | | | | |
| Root-collar diameter | --- | +0.819** | +0.770** | -0.150** | +0.017 | +0.025 |
| Total fresh weight | +0.819** | --- | +0.793** | -0.191** | -0.076** | -0.066** |
| No. first-order laterals | +0.770** | +0.793** | --- | -0.158** | +0.006 | +0.013 |
| Rating of fibrous root abundance | -0.150** | +0.191** | -0.158** | --- | +0.593** | +0.608** |
| % Short roots with Pt ecto. | +0.017 | -0.076** | +0.006 | +0.593** | --- | +0.992** |
| % Short roots with all ecto. | +0.025 | -0.066** | +0.013 | +0.608** | +0.992** | --- |

[1]Pt ecto. = *Pisolithus tinctorius* ectomycorrhizae.
[2]All ecto. = total ectomycorrhizae formed by all fungal species.
[3]** significant at the 1% level; N = 1,600.

Table 4.--Frequency distribution of the 1,600 longleaf pine seedlings analyzed for morphological attributes, by number of large first-order lateral roots and the rating of the abundance of fibrous roots

| Abundance of fibrous roots | Number of first-order lateral roots >1 mm: 0-2 | 3-5 | 6-8 | 9-11 | 12-14 | 15-17 | >17 | Total |
|---|---|---|---|---|---|---|---|---|
| | | | | Percent | | | | |
| Low | 2.69 | 6.12 | 7.69 | 5.06 | 4.31 | 2.19 | 0.75 | 28.81 |
| Medium | 11.81 | 12.69 | 13.25 | 8.38 | 5.38 | 3.37 | 1.62 | 56.50 |
| High | 3.81 | 3.75 | 3.12 | 2.44 | 0.50 | 0.69 | 0.38 | 14.69 |
| Totals | 18.31 | 22.56 | 24.06 | 15.88 | 10.19 | 6.25 | 2.75 | 100.00 |

Table 5.--Mean survival and vigor of longleaf pine seedlings in September of first growing season after outplanting on a sandhills site

| Nursery cultural treatment | Survival percentage | Vigor rating[1] |
|---|---|---|
| Lateral-root pruning | | |
| Pruned | 71.6 | 3.19 |
| Unpruned | 51.2 | 2.84 |
| Seedbed density | | |
| $6/ft^2$ | 60.9 | 3.20 |
| $12/ft^2$ | 62.0 | 2.84 |
| Drill spacing | | |
| 6 inches | 64.8 | 3.02 |
| 12 inches | 58.1 | 3.02 |
| Overall means | 61.4 | 3.02 |

[1]Rating of seedling vigor: 1 = very poor; 2 = poor; 3 = average; 4 = good; 5 = excellent (height $\geq$ 4 inches).

Table 6.--Linear correlations between survival and vigor of longleaf pine seedlings in September of first growing season and morphological attributes of bare-root stock

| Morphological attribute of bare-root stock | Field response of seedlings after 1 year: Survival | Vigor |
|---|---|---|
| | r value and significance level[1] | |
| Root-collar diameter | -0.063 | +0.509** |
| Total fresh weight | -0.157 | +0.432** |
| Length of needles | +0.008 | -0.124 |
| Number of strong lateral roots | -0.038 | +0.491** |
| Rating of fibrous roots | +0.553** | +0.203 |
| % Short roots with Pt ectomycorrhizae | +0.425** | +0.202 |
| % Short roots with all ectomycorrhizae | +0.427** | +0.226 |
| (Root-collar diameter) x (number of first-order lateral roots) | -0.025 | +0.536** |
| (Rating of fibrous roots) x (number of first-order lateral roots) | +0.264* | +0.645** |

[1]** and * significant at 1% and 5% level, respectively; N = 64.

Table 7.--Survival and vigor of seedlings in September of first growing season, by number of large first-order lateral roots and the rating of the abundance of fibrous roots

| Abundance of fibrous roots | Number of first-order lateral roots >1 mm: 0-2 | 3-5 | 6-8 | 9-11 | 12-14 | 15-17 | >17 |
|---|---|---|---|---|---|---|---|
| | | | | Survival (Percent) | | | |
| Low | 32 | 30 | 38 | 51 | 51 | 69 | 75 |
| Medium | 52 | 63 | 71 | 72 | 74 | 70 | 96 |
| High | 74 | 72 | 88 | 82 | 88 | 82 | 83 |
| | | | | Vigor rating[1] | | | |
| Low | 2.4 | 2.3 | 2.7 | 2.8 | 3.3 | 3.7 | 4.4 |
| Medium | 2.6 | 2.8 | 3.0 | 3.2 | 3.3 | 3.8 | 4.0 |
| High | 2.7 | 3.1 | 3.4 | 3.4 | 3.7 | 4.1 | 4.4 |

[1]Rating of seedling vigor: 1 = very poor, 2 = poor; 3 = average; 4 = good; 5 = excellent (height $\geq$ 4 inches).

# EFFECT OF TIME AND DEPTH OF PLANTING ON SURVIVAL AND GROWTH OF LOBLOLLY PINE (PINUS TAEDA L.) SEEDLINGS IN TEXAS[1/]

M. Victor Bilan[2/]

Abstract.--Loblolly pine seedlings were lifted from a nursery bed in two-week intervals (November 4-April 21) and were immediately planted in an open field. Each planting included seedlings planted at the root collar (A), one-half of shoot buried (B) and most of the shoot buried except for the one-inch terminal (C). Average mortality during the first year was 10%, 13% and 16% for the A, B and C planting depths, respectively; the corresponding values for the second year mortality were 2%, 3% and 5%. Average first year mortality by the planting periods ranged 7% - 24% with the highest values for April plantings. Deep (C) planting produced most height growth during the first growing season and least during the second and third growing seasons.

## INTRODUCTION

This study was initiated in 1958, during the period of intensified interest in survival of outplanted southern pine seedlings and in the successful establishment of pine plantations. Review of then available literature (Ferguson and Stephenson, 1955) concluded that some attempts have been made to rationalize the results in view of weather conditions and morphological development of planting stock. Slocum (1951) and Slocum and Maki (1956) reported that deep planting had some positive effect on growth of loblolly pine seedlings, but no literature was available dealing with the season of planting.

Preliminary experiments conducted by the author revealed that in East Texas roots of the pine seedlings were actively growing in the winter, so he had concluded that early planting would enable seedlings to develop sufficient root systems before the occurrence of the late spring and summer droughts. It was, however, necessary to determine the time in the autumn when seedlings in a nursery were "hardened" enough to be transplanted in a field without sustaining high mortality. It was also postulated that, other factors being equal, pine seedlings with well-developed deep-reaching root systems have a much better chance of surviving prolonged drought than the seedlings with superficial shallow root systems. This study was designed to plant seedlings in two-week intervals from November till April by using three different depths of plantings.

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## EXPERIMENTAL PROCEDURES

The study was established on a Woden sandy loam soil of old field in Nacogdoches County, Texas. The field was plowed and disked six weeks before the establishment of the experiment and then it was subdivided into three blocks, each 164 feet by 108 feet. Each block consisted of 41 rows, each 108 feet long and four feet apart. Two edge rows served as isolation strips, while the remaining 39 rows represented randomly assigned 13 different dates of planting at the three different depths. The plantings were made in two-week intervals beginning November 4, 1958 and ending April 21, 1959. Each row in a block contained 27 seedlings spaced four feet apart and planted on the same date and at the same depth. Two edge seedlings were considered as isolation.

The depths of planting were as follows: (A) root collar at the ground level, (B) one-half of the shoot buried, (C) most of the shoot buried except for the upper one-inch of terminal. Standard planting bar was used for regular (A) planting, while 18-inch bar was used for B and C planting depths. All roots were trimmed to the length of seven inches.

Statistically, this study consisted of 13 planting dates and three depths of planting, each represented by three replications of 25 seedlings. All data were analyzed by two-way analysis of variance.

## RESULTS

### Mortality

Periodic survey of experimental planting revealed that by March 19, 1959, attrition due gophers and weather damage was 6 percent, 4 percent and 2 percent in A, B and C planting depths, respectively (Table 1). Mortality was

particularly very high in November 18 planting, amounting to 22 percent in A and 16 percent in B depth of planting. It is important to notice that this planting was made just two days before the first freeze of the season. The loss due to inclement weather was four times as high as was the loss due to the obvious damage by gophers.

Average annual mortality for 1959 amounted to 10 percent, 13 percent and 16 percent in the planting depths A, B, and C, respectively (Table 2). Both April plantings suffered very high mortality in all depths of planting, averaging 19 percent, 21 percent and 33 percent in A, B and C, respectively. The highest mortality in A (25%) and B (27%) depths of planting occurred in planting made on November 18, while the highest mortality in C (36%) depth of planting occurred in April 21 planting.

Average mortality during 1960 growing season was 2 percent in A, 3 percent in B and 5 percent in C depth of planting, and no particular pattern was noticed in respect to the season of planting.

### Seasonal Height Growth

Average seasonal height growth in 1959 was significantly different for each depth of planting, amounting to 9 inches in A, 11 inches in B and 13 inches in C planting (Table 3). Seedlings planted on November 4 grew most, while those planted in March and April grew least, regardless of the depth of planting.

In 1960 and 1961, average height growth of A and B plantings was significantly higher than that of C plantings (Table 4), but in 1962 growth was identical in all depths of planting. Height growth of all April plantings continued to lag behind all others through 1960 and 1961 growing seasons.

### Total Height

Average height of all A plantings was greater than was the height of either B or C plantings from 1959 through 1962 (Table 5 and Table 6), while average height of all C plantings was significantly smaller than that of average B plantings. Average height superiority of November 4 planting was maintained in A plantings 1959 through 1961 and in B plantings 1959 through 1960. During four years of study, average height of trees planted in March and April was shorter than the height of trees planted in November-February in all depths of planting.

## DISCUSSION

Deep planting by burying shoot to one inch terminal reduced survival during the first two years and resulted in less height growth during the second and third year. The increased height growth during the first year did not compensate for less growth during the second and third year. Burying one-half of the shoot reduced survival and increased height growth during the first year only. Deep planted trees were shorter than the conventionally planted trees during four following years.

Slocum (1951) and Slocum and Maki (1956) reported that deep planting on well-drained clay did not effect survival and it increased height growth of loblolly pine seedlings through the second growing season, but the authors warned that similar results might not be expected elsewhere. Deep planting reduced survival of loblolly pine on droughty sandy loam (Ursic 1963) and poorly drained silt and clay soils (Switzer 1960) in Mississippi as well as on sandy loams in East Texas (Koshi, 1960).

The highest mortality in this study occurred in the seedlings lifted and planted before the first freeze in the fall or after broken shoot dormancy in April. It seems that high mortality in November 18 planting was caused by the first cold spell of the season, while root disturbance of the seedlings during the onset of shoot elongation was responsible for high mortality in the April plantings. Low temperature as the cause of high mortality in November 18 planting is supported by the fact that mortality was relatively low in the C depth of planting where only tips of the shoots were exposed to freezing atmosphere.

Poor survival of loblolly pine seedlings lifted prior to dormancy was reported by Venator and Barnett (1984), and Brissette and Roberts (1984) found less root regeneration potential in seedlings lifted in November. Bilan and Ferguson (1985) reported that all seedlings survived when they were lifted and outplanted in a field in two-week intervals December 1 through March 2.

Reduction of height growth in all March and April plantings during the first growing season resulted probably from the interruption of spring shoot elongation. Poor survival of loblolly pine seedlings lifted and planted during late spring was reported by Dierauf (1978) and Venator (1985). The author (Bilan and Ferguson 1985) found that loblolly pine seedlings lifted and planted in March grew less in height by early May than did seedlings lifted and planted December 1 - January 12.

The author concludes that loblolly pine seedlings have their highest survival and early growth potential when they are lifted and outplanted during their dormancy, but the actual survival and growth in the field may be to a great degree affected by the climatic conditions following outplanting.

Table 1. Average Attrition of Seedlings Due to Gophers and Weather by Time and Depth of Planting by March 19, 1959.

| DATE PLANTED | Planting Depth A | | | Planting Depth B | | | Planting Depth C | | |
|---|---|---|---|---|---|---|---|---|---|
| | GOPHER | DEAD | TOTAL | GOPHER | DEAD | TOTAL | GOPHER | DEAD | TOTAL |
| | - - PERCENT - - | | | | | | | | |
| NOV. 4 | 1.3 | 11.7 | 13.0 | 1.3 | 3.9 | 5.2 | 1.3 | 1.3 | 2.6 |
| 18 | 3.9 | 18.2 | 22.1 | 2.6 | 13.0 | 15.6 | 1.3 | 0 | 1.3 |
| DEC. 2 | 3.9 | 6.5 | 10.4 | 1.3 | 2.6 | 3.9 | 1.3 | 0 | 1.3 |
| 16 | 1.3 | 1.3 | 2.6 | 1.3 | 0 | 1.3 | 2.6 | 2.6 | 5.2 |
| 30 | 1.3 | 3.9 | 5.2 | 1.3 | 2.6 | 3.9 | 1.3 | 1.3 | 2.6 |
| JAN. 13 | 0 | 1.3 | 1.3 | 0 | 1.3 | 1.3 | 0 | 0 | 0 |
| 27 | 0 | 1.3 | 1.3 | 0 | 0 | 0 | 1.3 | 0 | 1.3 |
| FEB. 10 | 0 | 1.3 | 1.3 | 0 | 0 | 0 | 1.3 | 0 | 1.3 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AVERAGE | 1.3 | 5.1 | 6.4 | 0.9 | 2.6 | 3.5 | 1.2 | 0.6 | 1.8 |

Table 2. Average Annual Mortality of Loblolly Pine Seedlings by Time and Depth of Planting During 1959 and 1960.

| DATE PLANTED | Planting Depth | | | Planting Depth | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| | 1959 | | | 1960 | | |
| | - - PERCENT - - | | | | | |
| NOV. 4 | 7.4c[1/] | 16.0b | 12.3b | 2.5 | 2.5 | 5.0 |
| 18 | 24.7a | 27.2a | 9.9b | 0 | 3.7 | 2.5 |
| DEC. 2 | 9.9bc | 4.9c | 9.9b | 0 | 1.3 | 5.0 |
| 16 | 6.2c | 4.9c | 14.8b | 0 | 4.9 | 2.5 |
| 30 | 7.4c | 13.6bc | 17.3b | 2.5 | 0 | 7.4 |
| JAN. 13 | 2.5c | 9.9c | 14.8b | 3.7 | 3.7 | 2.5 |
| 27 | 4.9c | 4.9c | 9.9b | 1.3 | 1.3 | 2.5 |
| FEB. 10 | 4.9c | 7.4c | 7.4b | 6.2 | 7.4 | 8.6 |
| 24 | 11.1bc | 8.6c | 9.9b | 1.3 | 2.5 | 7.4 |
| MAR. 10 | 8.6c | 21.0ab | 18.5b | 3.7 | 7.4 | 3.7 |
| 24 | 7.4c | 11.1c | 13.6b | 1.3 | 3.7 | 0 |
| APR. 7 | 21.0ab | 22.2ab | 30.9a | 0 | 0 | 11.1 |
| 21 | 17.3ab | 19.8ab | 35.8a | 2.5 | 2.5 | 3.7 |
| AVERAGE FOR PLANTING DEPTH | 10.3a[2/] | 13.2b | 15.8c | 1.9a | 3.2ab | 4.8b |

1/ Values in individual columns for year 1959 followed by the same letters are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

2/ Average values for planting depth for 1959 and 1960 followed by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

Table 3. Average Annual Height Growth of Loblolly Pine Seedlings by Time and Depth of Planting for 1959 and 1960.

| DATE PLANTED | Planting Depth A | B | C | Planting Depth A | B | C |
|---|---|---|---|---|---|---|
| | | 1959 | | | 1960 | |
| | - | - | I N C H E S | | - | - |
| NOV. 4 | 14.4 a[1/] | 16.8a | 16.7a | 31.6a | 31.0a | 28.8a |
| 18 | 9.8b | 12.3b | 14.4a | 28.4a | 30.3a | 29.4a |
| DEC. 2 | 10.7b | 12.1b | 14.5a | 30.8a | 29.6a | 29.1a |
| 16 | 10.6b | 12.8b | 14.5a | 29.8a | 30.4a | 28.4a |
| 30 | 9.1b | 12.2b | 13.8b | 29.8a | 31.4a | 29.7a |
| JAN. 13 | 12.3a | 14.1b | 15.3a | 30.6a | 32.1a | 29.6a |
| 27 | 10.2b | 12.5b | 15.2a | 29.9a | 30.5a | 30.1a |
| FEB. 10 | 10.5b | 13.1b | 13.2b | 32.8a | 30.5a | 29.9a |
| 24 | 7.9bc | 11.7b | 10.6c | 29.2a | 27.6b | 28.1a |
| MAR. 10 | 5.5c | 7.9c | 10.3c | 28.0a | 24.7b | 27.1a |
| 24 | 6.7c | 8.3c | 10.2c | 29.2a | 29.7a | 28.8a |
| APR. 7 | 4.7c | 7.6c | 9.0c | 26.3b | 26.3b | 23.8b |
| 21 | 6.4c | 6.9c | 8.7c | 25.2b | 25.3b | 25.9b |
| AVERAGE FOR PLANTING DEPTH | 9.1c[2/] | 11.4b | 12.8a | 29.3a | 29.2a | 28.1b |

[1/] Values in individual columns followed by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

[2/] Average values for planting depth within years filler by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

Table 4. Average Annual Height Growth of Loblolly Pine Seedlings By Time and Depth of Planting for 1961 and 1963.

| DATE PLANTED | Planting Depth A | B | C | Planting Depth A | B | C |
|---|---|---|---|---|---|---|
| | | 1961 | | | 1962 | |
| | - | - | I N C H E S | | - | - |
| NOV. 4 | 50.0a[1/] | 49.9a | 46.5a | 48.5a | 49.0a | 52.0a |
| 18 | 45.8a | 49.4a | 46.8a | 50.5a | 51.3a | 47.2ab |
| DEC. 2 | 47.0a | 46.9a | 48.3a | 49.6a | 51.9a | 50.4ab |
| 16 | 45.8a | 47.1a | 47.1a | 48.4a | 51.0a | 51.0a |
| 30 | 46.4a | 46.6a | 47.3a | 50.7a | 53.2a | 51.1a |
| JAN. 13 | 48.0a | 50.4a | 44.8b | 49.6a | 50.8a | 46.7b |
| 27 | 49.8a | 47.0a | 49.2a | 50.9a | 51.1a | 50.6ab |
| FEB. 10 | 46.9a | 48.0a | 45.5a | 50.6a | 52.5a | 52.1a |
| 24 | 46.2ab | 49.2a | 43.1c | 50.1a | 51.2a | 48.7ab |
| MAR. 10 | 44.7b | 40.8b | 43.9b | 49.8a | 47.7a | 49.2ab |
| 24 | 47.7a | 47.6a | 43.5c | 50.7a | 49.2a | 50.1ab |
| APR. 7 | 43.5b | 43.5b | 42.0c | 47.6a | 46.5b | 47.8ab |
| 21 | 43.9b | 43.4b | 39.9c | 50.3a | 45.9b | 46.9b |
| AVERAGE FOR PLANTING DEPTH | 46.6a[2/] | 46.7a | 45.2b | 49.9a | 50.1a | 49.5a |

[1/] Values in individual columns followed by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

[2/] Average values for planting depth within years followed by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

Table 5. Mean total height of loblolly pine seedlings by time and depth of planting in 1959 and 1960.

| DATE PLANTED | Planting Depth 1959 A | B | C | Planting Depth 1960 A | B | C |
|---|---|---|---|---|---|---|
| | - | - | I N C | H E S | - | - |
| NOV. 4 | 24.4a | 21.8a | 17.7a | 56.0a | 52.8a | 46.5a |
| 18 | 19.8b | 17.3b | 15.4a | 48.2b | 47.6b | 44.8a |
| DEC. 2 | 20.7b | 17.1b | 15.5a | 51.5b | 46.7b | 44.6a |
| 16 | 20.6b | 17.8b | 15.5a | 50.4b | 48.2b | 43.9a |
| 30 | 19.4b | 17.2b | 14.8a | 49.2b | 48.6b | 44.5a |
| JAN. 13 | 22.3ab | 19.1b | 16.3a | 52.9b | 51.2b | 46.4a |
| 27 | 20.2b | 17.5b | 16.2a | 50.1b | 48.0b | 46.3a |
| FEB. 10 | 20.5b | 18.1b | 14.2a | 53.3b | 48.6b | 44.1a |
| 24 | 17.9bc | 16.7b | 11.6c | 47.1bc | 44.3bc | 39.7b |
| MAR. 10 | 15.5c | 12.9c | 11.3b | 43.5c | 37.6c | 38.4b |
| 24 | 16.7c | 13.3c | 11.2b | 45.9c | 43.0bc | 40.0b |
| APR. 7 | 14.7c | 12.6c | 10.0b | 41.0c | 38.9c | 33.8b |
| 21 | 16.4c | 11.9c | 9.7b | 41.6c | 37.2c | 35.6b |
| AVERAGE BY PLANTING DEPTH | 19.2[2/]a | 16.4b | 13.8c | 48.5a | 45.6b | 42.2c |

1/ Values in individual columns followed by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

2/ Average values for planting depth within years followed by the same letter are not statistical different at the 95 percent confidence level by Duncan's multiple range test.

Table 6. Mean Total Height of Loblolly Pine Seedlings by Time and Depth of Planting in 1961 and 1962.

| DATE PLANTED | Planting Depth 1961 A | B | C | Planting Depth 1962 A | B | C |
|---|---|---|---|---|---|---|
| | - | - | I N C | H E S | - | - |
| NOV. 4 | 106.0a | 99.7a | 93.0a | 154.5a | 148.7a | 145.0a |
| 18 | 94.0b | 97.0a | 91.6a | 144.5b | 148.3a | 138.8ab |
| DEC. 2 | 98.5b | 93.6a | 92.9a | 148.1b | 145.5a | 143.3a |
| 16 | 96.2b | 95.3a | 91.0a | 144.6b | 146.3a | 142.0a |
| 30 | 95.6b | 95.2a | 91.8a | 146.3b | 148.4a | 142.9a |
| JAN. 13 | 100.9b | 101.6a | 91.2a | 150.5a | 152.4a | 137.9ab |
| 27 | 99.9b | 95.0a | 95.5a | 150.8a | 146.1a | 146.1a |
| FEB. 10 | 100.2b | 96.6a | 89.6a | 150.8a | 149.1a | 141.7a |
| 24 | 93.3bc | 93.5a | 82.8b | 143.4b | 144.7a | 131.5b |
| MAR. 10 | 88.2c | 78.4c | 82.3b | 138.0c | 125.1b | 131.5b |
| 24 | 93.6bc | 90.6b | 83.5b | 144.3b | 139.8b | 133.6b |
| APR. 7 | 84.5c | 82.4c | 75.8c | 132.1c | 128.9b | 123.6c |
| 21 | 85.5c | 80.6c | 75.5c | 135.8c | 126.5b | 122.4c |
| AVERAGE FOR PLANTING DEPTH | 95.1[2/]a | 92.3b | 87.4c | 144.9a | 142.3b | 137.0c |

1/ Values in individual columns followed by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

2/ Average values for planting depth within years followed by the same letter are not statistically different at the 95 percent confidence level by Duncan's multiple range test.

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# ANNUAL AND GEOGRAPHIC VARIATIONS IN CONE PRODUCTION BY LONGLEAF PINE[1/]

William D. Boyer[2/]

Abstract--Cone production by longleaf pine (Pinus palustris Mill.) has been monitored on sample trees in shelterwood stands since 1966. Eleven locations, three each in Alabama and Florida and one in Louisiana, Mississippi, Georgia, South Carolina, and North Carolina were included in the study. Each location had two test areas, with 50 sample trees each. Six locations had 15 or more years of record, the others less. Annual counts of cones, conelets, and flowers (pistillate strobili) on each sample tree were made until trees were cut. Over 20 years, cone crops in which the average number of cones per tree exceeded 50 occurred only in 1967, 1973, and 1984. The frequency of cone crops potentially useable for natural regeneration (average of 20 or more cones/tree) varied considerably among locations. Cone crop frequency was very low (< 0.1 or 1 year in 10) at two locations in northwest Florida and one in southwest Georgia. Cone crop frequency reached a peak of 0.62 and 0.75 at two locations in central Alabama. The ratio of flowers counted to cones produced suggests that low cone crop frequencies near the Gulf Coast were due more to flower losses than failure to produce flowers.

## INTRODUCTION

Longleaf pine is a poor seed producer compared to other southern pines, and cone crops good enough for natural regeneration are relatively infrequent (Boyer and Peterson 1983). Wahlenberg (1946) noted that good crops occur every 5 to 7 years, and failures about 1 year in 5. In south Mississippi over a period of 21 years, there were 9 years in which medium or better cone crops occurred in longleaf pine (Maki 1952). Shelterwood stands in south Alabama produced 5 cone crops adequate for natural regeneration (> 50 thousand seeds/acre) over a period of 19 years (Croker and Boyer 1975). Heavy or bumper seed crops through much of the range of longleaf pine may occur once in 8 to 10 years (Maki 1952).

Very few systematic observations of cone production by longleaf pine have been reported, (e.g., Croker 1973, McLemore 1975). These are normally from a localized area and cover only a few years.

A region-wide test of the shelterwood system of natural regeneration of longleaf pine was initiated in 1966. Data obtained on cone and flower production at test sites have provided information on the variability of longleaf pine cone production over a period of time among several locations across the southeastern United States.

## METHODS

Natural regeneration tests for longleaf pine were established at 11 locations ranging from Louisiana to North Carolina (table 1). One test location was the Escambia Experimental Forest, Escambia County Alabama; four were National Forests in Louisiana, Mississippi, Alabama, and Florida; three were State forests in Florida, South Carolina, and North Carolina; two were private lands (Alabama and Georgia); and one was a military reservation (Florida).

At each of 10 locations (the experimental forest excluded), 2 test areas ranging from about 20 to 60 acres in size were established. One tested the two-cut and the other the three-cut shelterwood system. These tests were initiated from 1966 to 1970. Several two-cut tests were located on experimental forest sites. All tests were located in maturing stands of longleaf pine nearing end of a sawlog rotation. Within each test area, 25 sample points were established. The two seed trees nearest each sample point were marked for annual springtime counts of flowers and conelets using the method described by Croker (1971). Cones produced the preceding fall by each sample tree were also counted at the same time. This

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2/ Project Leader, George W. Andrews Forestry Sciences Laboratory, Auburn, AL, maintained by the Southern Forest Experiment Station, Forest Service, USDA, in cooperation with Auburn University.

Table 1.--Study sites and years of observation on longleaf pine cone production

| State | County | Years of observation |
|---|---|---|
| LA | Grant | 15 |
| MS | Perry | 8 |
| AL | Coosa | 8 |
| | Perry | 8 |
| | Escambia | 20 |
| FL | Santa Rosa | 18 |
| | Okaloosa | 15 |
| | Leon | 10 |
| GA | Decatur | 19 |
| SC | Chesterfield | 15 |
| NC | Bladen | 8 |

was the total of cones on the ground under the tree, plus a binocular count of cones remaining in the tree. Sample trees were not replaced when removed through thinning or natural mortality. The number of residual sample trees had dropped to less than 20 on only one area.

The sampling period reported here covers the 20 years from 1966 through 1985. Five locations were represented in the first year, and also the last. The number of years of observation at each of the 11 locations is given in table 1. The 20 years and 11 locations covered in this report result in a total of 220 cells. Of these, 144 included at least one observation (one test area). A total of 110 had two observations (both test areas at a location) and 7, all on the Escambia Experimental Forest, included observations from 3 test areas.

## RESULTS

### Annual Variation in Cone Production

Cone production by longleaf pine at all locations combined, in terms of average number of cones per tree, ranged from a low of 1 in 1966 to a high of 66 in 1973 (fig. 1). Cone production exceeded an average of 50 cones per tree only in 1967, 1973, and 1984. Cone production averaged less than 20 cones per tree in 13 of the 20 years and less than 10 cones per tree in 9 of the 20 years. Normally, an average of 750 cones per acre is needed to obtain adequate natural regeneration in a longleaf pine shelterwood stand. Shelterwood stands in this study averaged about 30 trees per acre, so an average of 25 cones per tree would be required for successful regeneration. Anything less than 20 cones per tree is likely to be ineffective.

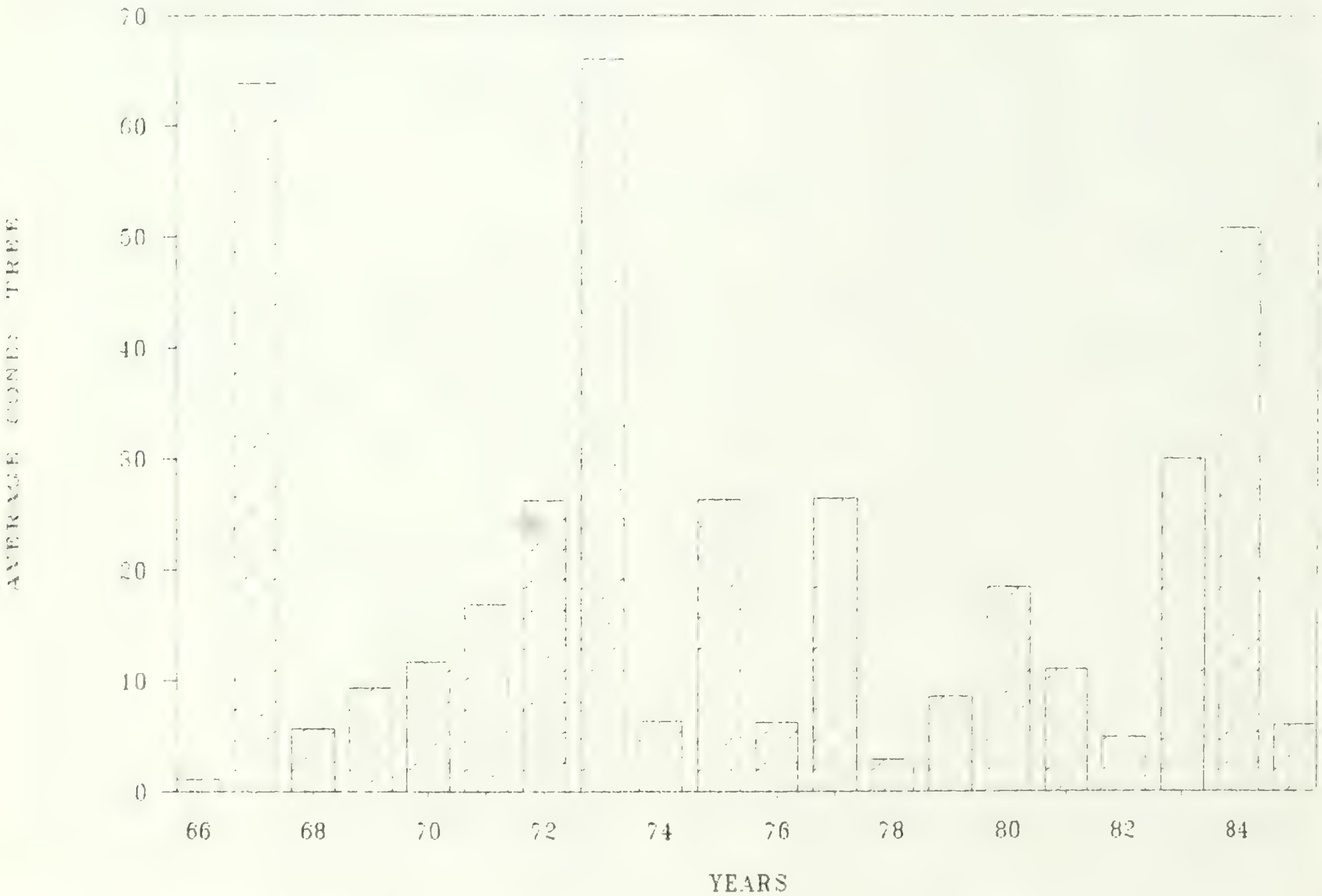


Figure 1.--Annual variation in cone production by longleaf pine for all locations combined.

## Variation among Locations in Cone Production

Average annual cone production per tree varied considerably among the 11 locations (table 2). The two locations in the Mountain Province of Alabama had the highest average cone production, with 71 and 86 cones per tree. Locations in northwest Florida and southwest Georgia had the lowest cone production.

Data on average annual cone production were derived from all sample trees for each year of observation. The years of observation varied among locations, and there were also differences among locations in seed-tree size, which affected cone production. All 11 locations provided cone production data for the 5 years from 1969 to 1973, inclusive. For these years, cones produced by sample seed trees in the 11- and 12-inch diameter classes only (10.6-12.5 in d.b.h.) were determined. This provided for a direct comparison of cone production among locations (table 2). Again, two northwest Florida sites and the southwest Georgia site had the lowest cone production.

The practical application of natural regeneration methods for longleaf pine depends on the frequency of cone crops large enough to provide acceptable regeneration. Considering an average of 20 cones per tree as a minimum, the frequency of cone crops this large or larger was determined for each location (fig. 2). These ranged from 0.75 and 0.62 for the two Mountain Province locations to 0, 0.06, and 0.07 for the three Florida-Georgia sites. The overall average frequency of useable cone crops was 0.30 or one crop every 3.3 years. All locations with cone crop frequencies of 0.10 or more have been successfully regenerated (6,000 or more established seedlings per acre), although sometimes this has

Table 2.--Longleaf pine cone production by location

| State | County | Cones per tree: All trees, all years | Cones per tree: 11-12 in d.b.h. trees, 1969-73 |
|---|---|---|---|
| | | -------Average number--------- | |
| LA | Grant | 33 | 14 |
| MS | Perry | 16 | 33 |
| AL | Coosa | 86 | 24 |
| | Perry | 71 | 80 |
| | Escambia | 13 | 12 |
| FL | Santa Rosa | 7 | 9 |
| | Okaloosa | 4 | 7 |
| | Leon | 19 | 12 |
| GA | Decatur | 3 | 5 |
| SC | Chesterfield | 30 | 21 |
| NC | Bladen | 7 | 17 |

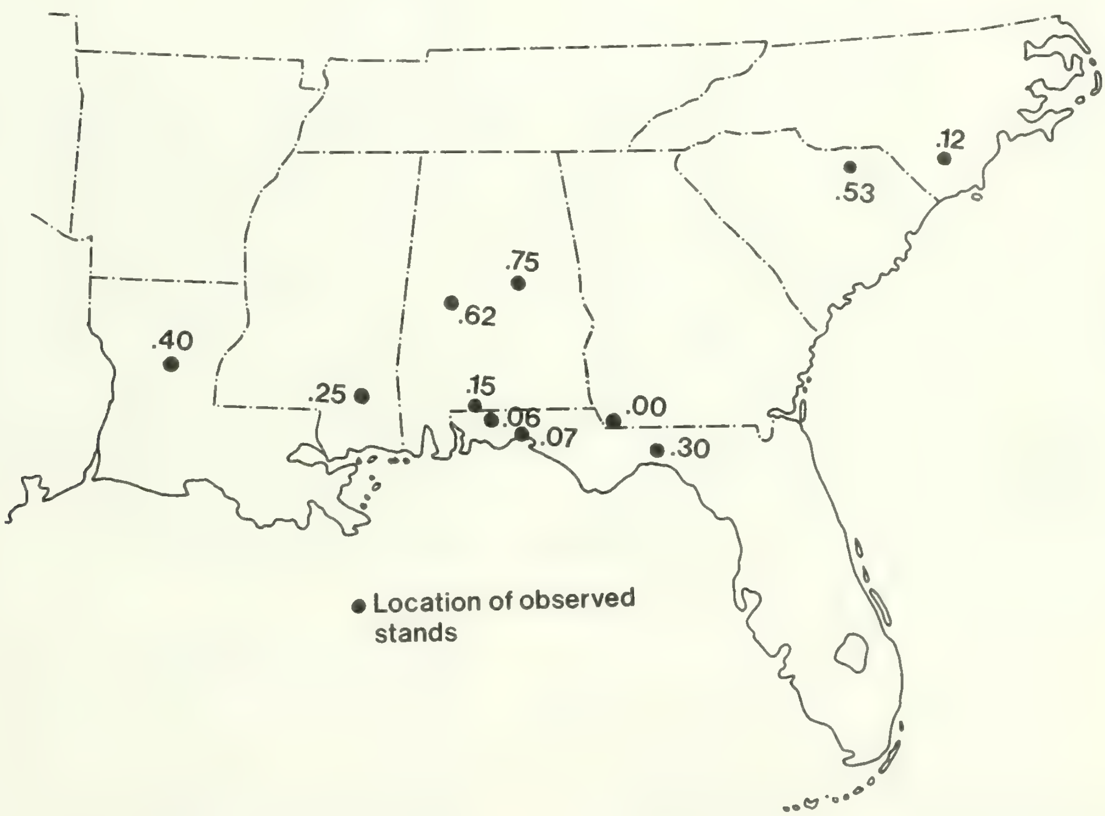


Figure 2.--Frequency of acceptable cone crops in longleaf pine.

been accomplished by two or more smaller cone crops (15-20 cones/tree) rather than a single large cone crop. The three locations with cone crop frequencies of less than 0.10 have not yet been regenerated.

Low cone crop frequencies could be due to failure of trees to flower or to loss of flowers and developing cones, or both. Flower counts (annual average/tree) are given in table 3. Cone counts on each area were compared to associated flower counts obtained from the same trees 2 years earlier and to conelet counts obtained 1 year earlier. The ratios of flowers to cones and conelet to cones were then determined (table 3). Cone crops on each test area during the first 2 years of observation were not counted at the flower stage, so ratios could not be determined for these years. For example, cones counted in the spring of 1967 were from the 1966 cone crop, but the flowers counted at the same time represented the 1968 cone crop.

Table 3.--Average annual flower counts and ratios of flowers to cones and conelets to cones

| State | County | Avg. No. flower counts/tree | Flowers /Cones | Conelets /Cones |
|---|---|---|---|---|
| LA | Grant | 36 | 4.1 | 0.66 |
| MS | Perry | 18 | 2.1 | 0.94 |
| AL | Coosa | 27 | 0.5 | 0.29 |
| | Perry | 23 | 0.5 | 0.23 |
| | Escambia | 28 | 3.3 | 0.72 |
| FL | Santa Rosa | 21 | 10.6 | 0.82 |
| | Okaloosa | 12 | 5.4 | 0.66 |
| | Leon | 16 | 26.2 | 1.13 |
| GA | Decatur | 18 | 13.7 | 1.13 |
| SC | Chesterfield | 30 | 1.2 | 0.43 |
| NC | Bladen | 5 | 0.9 | 0.48 |

Flower production among the 11 locations was much more uniform than the resulting cone production (coefficient of variation of 41 percent for flowers vs. 106 percent for cones). The ratios indicate considerable variation among locations in both flower losses during the first year and losses of developing cones during the second year (table 3). Higher values indicate greater losses. The highest flower losses were recorded at two Florida sites plus the Georgia site. These same sites also had higher than average losses of developing cones. Conversely, the high cone-producing sites in Coosa and Perry Counties, Alabama had the lowest losses of both flowers and developing cones.

An analysis of variance of all data on flower and cone counts indicated that for flowers, the variation associated with year (33 percent) was nearly double that associated with location (18 percent). For cones, the variation associated with location (26 percent) was greater than that associated with year (18 percent). Flower production is highly variable from year-to-year, and in large part this reflects climatic conditions before initiation. Flower losses, however, appear to be associated with location, being more severe some places than others. Final cone crop size, therefore, reflects factors affecting initial flowering and also flower and cone losses.

## CONCLUSIONS

Production of longleaf pine cones varies considerably from year-to-year and from place-to-place. Considering the region as a whole, the frequency of cone crops large enough to establish natural regeneration in shelterwood stands is almost 1 year in 3. Among the locations sampled, however, frequency of useable cone crops ranged from 3 years out of 4 to zero. Three locations had cone crop frequencies of less than 1 year in 10. At locations such as these, natural regeneration of longleaf pine may not be a viable option.

Over time, flower production is more consistent among locations than cone production. The evidence in this study suggests that low cone production is associated more with flower losses and, to a lesser extent, cone losses than with failure to flower in the first place.

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EVALUATION OF SEED VIGOR IN LONGLEAF, SHORTLEAF,

VIRGINIA, AND EASTERN WHITE PINES [1]

F. T. Bonner[2]

Abstract.--Multiple seed lots of longleaf (Pinus palustris Mill.), shortleaf (P. echinata Mill.), Virginia (P. virginiana Mill.), and eastern white (P. strobus L.) pines were used to evaluate measurements of seed vigor for prediction of seedling emergence in nursery bed environments. The highest correlations with seedling emergence were obtained with the germination test parameters--percent germination and peak value and with electrical conductivity measurements of seed leachate with the ASAC-1000 Seed Analyzer. Correlation coefficients differed only slightly. Conductivity measurements were best for shortleaf, Virginia, and eastern white pines (r= 0.790, 0.774, and -0.888), and germination test parameters were best for longleaf (r= 0.858 and 0.957). In five of six tests, percent germination and peak value were more highly correlated with seedling emergence than Czabator's germination value. The data suggest that these four species are similar to other southern pines in test responses. A good laboratory test is desirable, but the conductivity test is an able substitute when time is limiting. Interpretation of the test results for optimum utilization of seeds in nurseries is discussed.

## INTRODUCTION

The frequent inability of laboratory germination tests to accurately predict nursery germination has been a common problem for nursery managers. When field conditions are favorable, there are few problems. But when bed environments are stressful, standard, germination test percentages may not be adequate predictors of seed performance.

Barnett and McLemore (1984) concluded that germination tests to accurately predict nursery germination percentages were the best predictors of seedling production in stratified loblolly (Pinus taeda L.) and slightly dormant slash pine (P. elliotti Engelm), and that Czabator's germination value (GV) (Czabator 1962) was best for dormant or slowly germinating lots. Earlier work in our laboratory (Bonner 1985) agreed with the use of germination percentages, but we found peak value (PV), another Czabator parameter, to be a better predictor than GV.

[1] Paper presented at Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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Leachate conductivity measurements were also very promising for loblolly and slash pines (Bonner 1986), as well as for some other conifers (Bonner and Vozzo 1986).

Other southern pines have been included in research on seed vigor test methods at the author's laboratory from 1976 to 1985. This paper summarizes results obtained in 1983-85 with four of them: longleaf (P. palustris Mill.), shortleaf (P. echinata Mill.), Virginia (P. virginiana Mill.), and eastern white (P. strobus L.) pines.

## MATERIALS AND METHODS

Multiple seed lots of varying ages and geographic sources were assembled for testing. Until used, they were stored at 3°C with moisture contents of 10 percent or lower. Samples were taken from as many as 22 and as few as 10 seed lots of each 2 years. Some seed lots were used in both years. Laboratory germination, leachate conductivity, tetrazolium staining (longleaf and eastern white pines only), and nursery germination tests were conducted on all lots. The correlation of test parameters with nursery emergence was used to evaluate the effectiveness of the tests.

Laboratory germination.- Germination tests were carried out under official test conditions (Association of Official Seed Analysts 1978). Four

replications of 50 to 100 seeds each were germinated in cabinet germinators on moist blotters for 28 days. Test temperatures were 30°C for 8 hours of light, followed by 16 hours of darkness at 20°C. Germination was counted a minimum of three times a week to facilitate calculation of rate parameters. In Czabator's formula, PV is the highest quotient obtained by dividing cumulative percent germination on each day by the number of days elapsed. This value on the last test day is the mean daily germination (MDG); thus, GV = (PV) (MDG).

Eastern white pine was stratified for 28 days at 3°C, but longleaf received no stratification. Virginia and shortleaf pine seeds were stratified for 14 days at 3°C in the 1984 tests. These species received no stratification in the 1985 tests because the treatment was detrimental to the lower quality seed lots in 1984.

Leachate conductivity.- Samples of 100 seeds (four per lot) were leached in deionized water for 24 hours at room temperature. Current flow (μamp) through the leachate of individual seeds was measured with an automatic seed analyzer manufactured by Neogen Food Tech.,Inc., [3] Models 610 and ASAC-1000 were both used, but primarily the latter. Means and standard deviations of conductivity and germination estimates based on the histogram segment (HS) method were calculated as described by Bonner and Vozzo (1986).

Tetrazolium staining (TZ).- Seeds from 50-seed samples were cut down one side with fingernail clippers and soaked in deionized water for 24 hours at room temperature. Then they were placed in a 0.5-percent solution of 2,3,5-triphenyl tetrazolium chloride, pH 6.5 to 7.0, at 20°C for 18 to 24 hours in the dark. Seeds were scored as "good" or "bad" according to the criteria of Moore (1971), and vigor was expressed as the percentage of "good" seeds in the sample. TZ staining was used on longleaf and eastern white pines in 1 year only.

Nursery emergence.- Four 50- or 100-seed samples were planted in completely randomized rows in nursery beds at the Forestry Sciences Laboratory. Longleaf seeds were sown on the surface and pressed into the soil with a board. The other species were planted about 3 mm deep. All plots were mulched with chopped pine straw and protected by bird netting. Eastern white pine was stratified 28 days at 3°C. Virginia and shortleaf pines were stratified 14 days in the 1984 tests and 21 days in the 1985 tests. Longleaf received no stratification. All tests were planted in April, and emerging seedlings were counted one to three times per week until emergence was complete.

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[3] Mention of trade means is for information only and does not imply endorsement or recommendation by the U.S. Department of Agriculture of any product or service over others that may also be available.

Data analysis.- Correlation coefficients between test parameters and nursery emergence were calculated, and significance was tested with the "t" test (p=0.05). We assumed that the test parameters that were consistently significantly correlated with nursery emergence should be considered as valid estimates of seed vigor.

RESULTS

Longleaf pine.- Both laboratory germination and leachate conductivity estimates showed strong significant correlations with nursery emergence and survival in the first test year (table 1.) In the second year, all "r" values were lower, and germination test parameters were much better than those in other tests. Although TZ staining was significantly correlated with nursery factors in 1983, the test was dropped from further consideration because of the difficulties encountered in standardizing interpretation of staining patterns. The highest "r" values obtained were from percent germination, mean conductivity, and PV.

Shortleaf pine.- Nursery germination was so poor in 1984 that no measurements were taken. In the 1985 test, significant correlations with nursery performance were obtained from percent germination, PV, GV, and germination estimates from leachate conductivity (table 2). Conductivity estimates gave the highest "r" values, then PV.

Virginia pine.- Results with Virginia pine were very similar to those obtained with shortleaf pine (table 2). After nursery test failure in 1984, the 1985 results showed the highest "r" values from conductivity estimates. All laboratory germination test parameters were also significantly correlated with emergence and survival.

Eastern white pine.- Leachate conductivity and laboratory germination parameters showed significant correlations with emergence and survival in the nursery plots (table 3). The highest "r" values were obtained with mean conductivity for emergence in both years and with percent germination for survival in 1984. There was little difference among these values, however, Among germination test parameters, percent germination and PV coefficients were always higher than the coefficients for GV.

DISCUSSION

Results from these tests were very similar to results reported previously for loblolly and slash pines (Bonner 1986). Laboratory germination parameters and leachate conductivity measurements were about equal in their correlation with nursery emergence.

Standard, but time consuming, laboratory tests are always desirable for proper seed management decisions, but rapid estimates of seed quality also have their place. In many situations, seeds must be planted or shipped before a germination test can be scheduled and completed. Leachate conductivity tests can apparently fill that need. Other rapid tests, such as TZ or X-ray, may be just as accurate, but each has serious drawbacks in subjective interpretation or time-consuming methodology.

Table 1.--Correlation coefficients (r) between vigor estimates and nursery emergence and survival for longleaf pine

| | 1983 | | 1984 | |
|---|---|---|---|---|
| Vigor estimates[a/] | Percent emergence | Percent emergence | Percent emergence | Percent survival |
| | ----------- | ----------- r | ----------- | ----------- |
| Percent germination | 0.957* | 0.955* | 0.858* | 0.836* |
| GV | .880* | .909* | .853* | .838* |
| PV | .954* | .940* | .856* | .830* |
| Conductivity mean | -.824* | -.908* | -.664* | -.612* |
| Conductivity SD | -.922* | -.915* | -.250 | -.274 |
| Conductivity HS | -- | -- | .549* | .458 |
| TZ | .779* | .750* | -- | -- |

a/ GV, germination value; PV, peak value; Conductivity, SD (standard deviation), HS (histogram segment); TZ, tetrazolium staining.

* Significant at p = 0.05.

Table 2.--Correlation coefficients (r) between vigor estimates and nursery emergence and survival for shortleaf and Virginia pines in 1985

| | Shortleaf | | Virginia | |
|---|---|---|---|---|
| Vigor estimates | Percent emergence | Percent survival | Percent emergence | Percent survival |
| | ----------- | ----------- r | ----------- | ----------- |
| Percent germination | 0.744* | 0.618* | 0.697* | 0.583* |
| GV | .622* | .540* | .688* | .570* |
| PV | .748* | .647* | .676* | .765* |
| Conductivity HS | .790* | .675* | .774* | .616* |

*Significant at p = 0.05.

Table 3.--Correlation coefficients (r) between vigor estimates and nursery emergence and survival for eastern white pine [a/]

| | 1983 | | 1984 | |
|---|---|---|---|---|
| Vigor estimates | Percent emergence | Percent survival | Percent emergence | Percent survival |
| | ----------- | ----------- r | ----------- | ----------- |
| Percent germination | 0.857* | -- | 0.845* | 0.748* |
| GV | .784* | -- | .727* | .622* |
| PV | .860* | -- | .794* | .669* |
| Conductivity mean | -.869* | -- | -.888* | -.726* |
| Conductivity SD | -.545* | -- | -.591* | -.484 |
| Conductivity HS | -- | -- | .717* | .593* |
| TZ | .208 | -- | -- | -- |

a/ No survival counts were taken in 1983.

* Significant at p = 0.05.

In five of the six primary tests in these studies, percent germination and PV were more highly correlated (larger "r" values) with seedling emergence than GV. The same was true with loblolly and slash pines (Bonner 1986), although differences for all six species were very small. Other researchers have shown a direct relationship between germination rate and seedling quality of southern pines (Boyer and others 1985; Barnett and McLemore 1984; Wasser 1978). Therefore, it seems there are good reasons for making more use of germination rate in evaluation of seed lots.

Under the conditions of these studies, minimum PV values for "high-quality" seed lots can be suggested: eastern white pine - 3.0; shortleaf pine - 3.5; longleaf pine - 4.0; and Virginia pine - 5.0. These values assume removal of empty seeds by proper seed cleaning, and they may differ slightly under different test conditions. When test results show PV's above these levels, normal stratification periods should be used: Virginia pine - 14 days; shortleaf pine - 14 to 28 days; and eastern white pine - 30 to 60 days. Longleaf pine should not be stratified. If PV's are below the suggested values, stratification periods should be shortened by about one-third to avoid damage to the seeds.

Since more vigorous seeds will germinate better at low temperatures than weak seeds, seed lots with the higher PV's should be sown first when soil temperatures are usually lower. Less vigorous lots (PV below the minimum) should do better when soil temperatures are higher. The best utilization of seeds, however, will result from the nursery manager knowing how each of the seed sources react to stratification and conditions of the nursery. With the current practice of repeatedly sowing with the same families or seed sources from the same orchards year after year, there is no reason why this information should not be available.

Interpretation of leachate conductivity data is not well-defined at this time. Both mean conductivity and estimates by the MS method have been reliable in certain situations. However, seed conditions can influence the conductivity/vigor relationship in many cases (Vozzo 1984; Vozzo and Bonner 1986), and additional research must be done to develop this promising technique. Most seed managers would sacrifice a certain amount of accuracy to get an estimate of quality in 24 hours as compared to the 30 or 60 days of a germination test.

## CONCLUSIONS

Laboratory germination tests and seed leachate conductivity measurements can be used to evaluate seed vigor in longleaf, shortleaf, Virginia, and eastern white pines. Total germination and PV, a measure of germination rate, are preferred parameters of germination tests. Electrical conductivity measurement shows great promise as a rapid estimate of vigor.

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# THE EFFECT OF SEED TREATMENT AND SOWING METHOD ON GERMINATION OF OCALA SAND PINE [1/]

Kenneth W. Outcalt [2/]

Abstract.-- Ocala sand pine (Pinus clausa var. clausa D. B. Ward) seeds, half of them presoaked and half untreated, were sown in a greenhouse study in fine sand soil at moisture contents (by weight) of 2, 5, and 10 percent by pressing into the soil, by broadcasting and covering with soil, or by broadcasting and covering with soil which was packed. In a second test presoaked and control seeds were sown in soil at 3, 5, and 7 percent moisture by pressing into the soil. Soil at 2 percent moisture content was too dry for any germination even if seeds were presoaked. The seeding method had no effect on speed of germination or total germination. Presoaking seeds resulted in more rapid germination in both tests and at the 5 percent soil moisture content an increase in total germination of about 20 percent in the first test. Most of the time soil moisture will be between wilting point, about 2 percent, and field capacity, about 10 percent. Thus, presoaking may be a way to increase seed germination. In addition presoaking could reduce losses to predation by speeding up germination. Although presoaking appears beneficial and did not have any negative effects on viability of seeds lying in dry soil, field tests are needed before a final evaluation can be made.

## INTRODUCTION

Ocala sand pine (Pinus clausa var. clausa D.B. Ward) is native to the droughty, acid, infertile, marine deposited sandhills of Florida. The largest concentration occurs in the center of the state on an area known as the Central Highlands. The understory is primarily evergreen shrubs 6 to 10 feet tall with very little herbaceous ground cover (Laessle 1958). Typical understory species are sand live oak (Quercus virginiana var. geminata (Small) Sarg.), myrtle oak (Q. myrtifolia Willd.), Chapman oak (Q. chapmanii Sarg.), and palmetto (Sabal spp.). This area has hot, humid summers, somewhat dry winters, and a long growing season of 269 to 312 days. Precipitation is abundant, 53 to 60 inches per year, and is fairly well distributed (Burns and Hebb 1972).

Sandhills soils are acid, infertile and droughty marine deposits from the interglacial stages of the Pleistocene epoch. Because of sorting action during deposition, they are largely quartz sands, ranging from a few feet to more than 20 feet deep. Organic matter content is low because the climate promotes rapid oxidation. Because of the low levels of organic matter and of clay colloids, cation exchange capacities and moisture retention of these soils are low (Burns and Hebb 1972). Due to the soil's low moisture-holding capacity, drought conditions can exist within 2 weeks of a heavy rainfall. Also surface temperatures of exposed soils may reach 140° F on summer days, which is why these areas have been called deserts in the rain (Burns and Hebb 1972).

Ocala sand pine begins cone production at an early age, about 5 years, and has abundant annual crops (Barnett and McLemore 1965). The cones are predominately serotinous and persist on the tree for many years. Most natural stand have originated from seed released by the serotinous cones following wildfires. Attempts have been made to get natural regeneration by using the heat from the sun to open cones in logging slash, but stocking has been below acceptable levels (Price 1973). Burning logging slash to release seeds has also been tried, but it gave poor results because available cones were unevenly distributed and the fire destroyed many seeds (Cooper et al., 1959).

Ocala sand pine can be planted, but due to its lack of true winter-type dormancy (Zelawski and Strickland 1973), survival is generally poor, about 60 percent, and variable (Burns and Hebb 1972, Hebb and Burns 1973). The most successful and economical system for regeneration has been clearcutting, site preparation, and direct seeding (Price 1973). Seed is broadcast at a rate of 0.5 to 1.0 pound per acre following site preparation by double chopping with a heavy, duplex brush cutter. Research and experience has shown that

1/ Paper presented at Southern Silvicultural Research Conferrence, Atlanta, Georgia, November 4-6, 1986.

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some method of covering the seed with a layer of soil 0.25 to 0.75 inches thick will reduce seed predation and increase germination (Burns and Hebb 1972).

Although broadcast seeding has been the most successful system for regeneration of Ocala Sand Pine it has not been entirely satisfactory. Many areas, especially during years with extended drought periods, which occur about 3 years out of 10, fail to regenerate adequately. In addition many areas are overstocked and require precommercial thinning to prevent stand stagnation. In an attempt to improve spacing, eliminate precommercial thinning, and reduce costs, a new system using a bracke scarifier-seeder was recently employed. This system was very successful the first year, but since then almost all of the areas seeded with it have failed, as have the majority of the areas that were broadcast seeded. If the success ratio could be improved by even a small margin it would result in considerable savings. Two areas where gains might possibly be made are improving the seeding method or pretreating the seed.

The specific purpose of this study was to determine if packing the soil over the seed or presoaking the seeds in water would increase germination and if there were any interactions between packing, soil moisture content, presoaking and germination.

## METHODS

A sample of the Ocala sand pine seed from four different seed lots being used for regeneration during the 1985-86 season was obtained from personnel on the Ocala National Forest. All seeds were from cones collected on the Ocala National Forest and processed by the National Tree Seed Laboratory. Processing included extraction, cleaning, and coating with Arasan and Aluminum powder. Prior to study initiation seeds were tested for viability on germination paper in boxes at the Olustee Laboratory, Florida. Because all lots had similar and high viabilities of about 80 percent, all tests were done using a mixture of seeds from all lots.

A split-plot factorial design was used in both portions of the study. All germination tests were done in 6.75 x 4.75 x 2.25 inch germination boxes under greenhouse conditions at the Olustee Laboratory. Control seeds were planted in half of each germination box and presoaked seeds in the other half. Presoaking was done in tap water at 38° F for 24 hours. Upon removal from cold storage the water was drained from soaked seeds and they were blotted dry enough with towels so they would not stick together and then planted. In the first test, soil from the E horizon of a Blanton fine sand (loamy, siliceous, thermic grossarenic paleudult) with moisture content by weight of 2, 5, or 10 percent was used in factorial combinations with seed planted three ways: by pressing into the soil; broadcasting and covering with soil; or broadcasting and covering with soil which was then packed. these moisture levels were chosen to represent effective wilting point, minimally adequate, and field capacity and the methods were to simulate drilling in seeds, the present system of sowing, and present system with the addition of a packing wheels, respectively. In the second test the surface A and E horizons from a Paola sand (hyperthermic, uncoated spodic quartzipsamment) soil at moisture contents of 3, 5, and 7 percent with three replications was used and all seeds were planted by pressing into the soil.

The number of seedlings emerging from the soil was counted in each box at weekly intervals for three weeks following sowing. At the end of the initial three weeks in the second study, enough moisture was added to the boxes that originally had 3 percent water to bring them to 10 percent and these were monitored for an additional three weeks. Percent germination data were analyzed by analysis of variance for each test by individual week.

## RESULTS AND DISCUSSION

There was not enough moisture available at the 2 percent level for any germination to occur. This was expected since this moisture level was included to represent soil at the effective wilting point. Germination was also very limited (about 3 percent) at the 3 percent soil moisture level. The sowing method used had no effect on total germination which was 79, 77, and 74 percent for broadcast, cover and pack; drill; and broadcast and cover, respectively. As could be expected, total germination increased with percent soil moisture (Table 1 and 2). Presoaking seeds significantly increased the speed of germination, especially in the first test. The increased speed of germination may be due to the higher moisture level of presoaked seeds, 22 versus 8 percent for normal seeds, since it is quite likely seed must reach a critical moisture level before certain physiological processes necessary for germination can begin. However, presoaking may just increase the ability of the seeds to imbibe water, since Barnett and McLemore (1965) found soaking sand pine seeds in 95 percent ethanol also increased the speed of germination. In the first test presoaking also increased total germination at the 5 percent soil moisture level (Table 1). It may be that with limited moisture the presoaking allows a few more of the seeds to reach the critical level. The results of the second test, however, were contradictory as total germination was not effected at any soil moisture level by presoaking (Table 2). This may be due to the lower overall germination rate of this test.

Table 1.-- Effect of presoaking on germination of Ocala sand pine seed at soil moisture contents of 5 and 10 percent.

| Days after sowing | Treatment | Germination at soil moisture level 5-percent | 10-percent | mean |
|---|---|---|---|---|
| | | | Percent | |
| 6 | Presoaked | 25 | 23 | 24a[1/] |
| | Control | 7 | 3 | 5b |
| | Mean | | 16 | 13a |
| 12 | Presoaked | 71 | 76 | 73c |
| | Control | 37 | 53 | 45d |
| | Mean | 54c | 65c | |
| 21 | Presoaked | 79 | 85 | 82e |
| | Control | 56 | 85 | 71e |
| | Mean | 68f | 85e | |

1/ Means within a row or a column for each data not followed by the same letter are significantly different at the .05 level.

Table 2.--Effect of presoaking on germination of Ocala sand pine seed at soil moisture contents of 5 and 7 percent.

| Days after sowing | Treatment | Germination at soil moisture level 5-percent | 7-percent | mean |
|---|---|---|---|---|
| | | | Percent | |
| 7 | Presoaked | 18 | 29 | 24a[1/] |
| | Control | 8 | 15 | 12b |
| | Mean | 13a | 22b | |
| 14 | Presoaked | 25 | 58 | 42c |
| | Control | 25 | 42 | 34c |
| | Mean | 25c | 50d | |
| 21 | Presoaked | 25 | 61 | 43c |
| | Control | 25 | 49 | 37c |
| | Mean | 25c | 55d | |

1/ Means within a row or a column for each data not followed by the same letter are significantly different at the .05 level.

Seed losses to predators can and often are a substantial problem in artificial regeneration of Ocala sand pine stands by direct seeding. Cooper et al. (1959) concluded that the loss of seed to rodents, birds, and ants was the single largest obstacle to the successful regeneration of Ocala sand pine by artificial seeding. Presoaking Ocala sand pine seed before sowing seems to be a simple way to speed up the rate of germination. This would be advantageous under field conditions since the sooner the seed germinates and begins growth the less time it is exposed to the dangers of predation. In addition this study indicates that under some conditions presoaking may also increase total germination.

One of the possible disadvantages of presoaking seeds could be the loss of viability if sown in very dry soils. This could occur if presoaking caused seeds to begin germination at soil moisture levels that were too low for successful completion of seedling emergence or if presoaking changed the physiological state of the seed such that it was more susceptible to damage while lying in the soil waiting for precipitation to raise the soil moisture level enough for germination to occur. In this study, if moisture levels were too low, seeds did not begin germination even if presoaked and there was no evidence that presoaking seeds reduced their viability while lying in soil at low moisture levels. When water was added to soil after 3 weeks of simulated drought conditions both presoaked and control seeds had an equal germination rate, about 53 percent. This was essentially equal to the 55 percent rate for seeds sown in soil which initially had adequate moisture for germination.

Although presoaking Ocala sand pine seeds appears promising it should be tested under field conditions before it is adopted for general use. This will be done very soon by using presoaked seed in one seed box and control seed in the other of a two row bracke seeder on some operational seeding jobs on the Ocala National Forest.

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A Comparison of Natural Regeneration Alternatives for a Loblolly Pine Forest in the Lower Piedmont of Georgia[1/]

M. Boyd Edwards[2/]

Abstract.--Research is currently underway to quantify and demonstrate effective natural regeneration alternatives for a loblolly pine forest in the lower Piedmont of Georgia. These alternatives include: (1) clearcut with seed in place, (2) clearcut with seed in place and preharvest burn, (3) seed tree method, 4) seed tree method with preharvest burn, (5) shelterwood method, and (6) shelterwood method with preharvest burn. This paper reviews the progress of pine establishment at 3 years after harvest and indicates that all treatment methods have potential to achieve full stocking.

## INTRODUCTION

Today there are numerous silvicultural methods that serve to regenerate a loblolly (Pinus taeda L.) pine forest. However, most land managers and landowners are interested in economically sound methods that can be successfully accomplished in an ecologically attractive manner. In recent years, many thousands of acres have been cut and left without any attempt to effectively regenerate them. This scenario is followed all too often and its use centers around a group of landowners that we define as nonindustrial private forest (NIPF) landowners. The majority of NIPF lands have been cut and left because they were cut without consideration as to how to regenerate them. The primary concern was to harvest because money was needed by the landowners. Unfortunately, when the need to regenerate the depleted forest land was finally considered the landowner was shocked to find the expense too great through usual site preparation and planting methods. Figure 1 illustrates the importance of NIPF ownership in terms of the amount of lands that they control in Georgia. It is obvious that if we wish to meet future demands for pulp, lumber, and fiber demanded by our economy, we must find methods by which these landowners can effectively regenerate their forest lands.

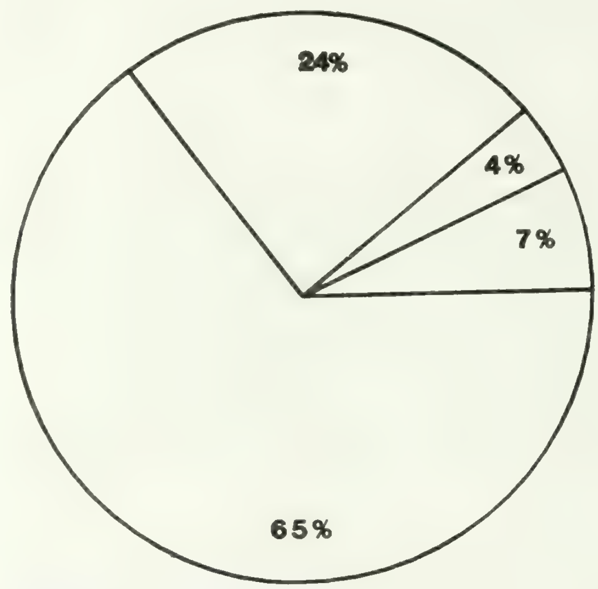


Figure 1.--Georgia commercial forest ownership in 1982: Private ownership (65%), industry owned (24%), industry leased (4%), public (7%).

If it is possible to reverse this scenario through education of this group of landowners to the point where they will consider the need for regeneration and how they plan to do it prior to harvest, we have a good chance of effectively regenerating our loblolly pine forests through natural methods. The purpose of this study is centered on the need for ecologically sound and cost-effective alternatives for regeneration of loblolly pine sites.

The study area is in Jones County, Georgia, on the Hitchiti Experimental Forest, 20 miles north of Macon. It is a 100-acre tract which supported a mixture of pine and hardwood that regenerated naturally after cotton fields were abandoned in the 1930's. This situation is typical of many forested sites in the lower Piedmont today.

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## METHODS

The study began in spring 1982 when five replications of six treatments were laid out in a randomized block experimental design. Individual permanent 2.0-acre rectangular plots for each treatment were installed on each block. The following treatments were assigned to the plots:

1. Clearcut with seed in place and no preharvest burn. This serves as the control.
2. Clearcut with seed in place, with preharvest burn.
3. Seed tree cut with 8 to 10 seed trees per acre after harvest and no preharvest burn.
4. Seed tree as in treatment 3, with preharvest burn.
5. Shelterwood cut that reduces stand to 25 square feet of basal area per acre and no preharvest burn. The removal cut is scheduled 5 years after harvest.
6. Shelterwood cut as in treatment 5, with preharvest burn.

After the 2-acre square plots were delineated on the ground, a complete inventory was made of all merchantable trees on each plot. With these data in hand, residual trees were selected for all but the clearcut plots. Trees selected as seed trees were straight, had good form, were free from injury and disease, and were observed to have numerous cones present. Residual trees were well distributed across each plot for good seed coverage when dispersal occurs. Residual stand conditions are described in table 1.

Prior to harvest, a summer burn was conducted on one-half the treatments. This portion of the treatment was accomplished by strip headfires that consumed the understory vegetation but did not damage the overstory. The duff layer was reduced to less than 1-inch throughout the areas burned and served to improve.the seedbed significantly. The burning was timed so that it occurred prior to seedfall.

The harvest cut was made in the spring of 1983 with a total of 823 M fbm of pine logs and 355 M fbm of pine roundwood removed from the 100-acre study area. Care was taken to ensure that no damage occurred to the selelcted seed trees in the harvesting process. During the summer of 1983, all hardwood stems 1-inch d.b.h. or larger on all of the 2-acre treatment plots were injected with Tordon 101, .

After harvest, four permanent milacre sample plots were installed on each treatment plot for the purpose of determining the number of pine seedlings established at 1, 2, and 3 years after harvest.

Table 1.--Residual plot inventory data, by treatment, 1982

| Block | Plot | Treatment | Preharvest burn | Seed trees per treatment | Mean d.b.h. | Basal area /acre | Mean ht. |
|---|---|---|---|---|---|---|---|
| | | | | No. | Inches | $Ft^2$ | Feet |
| 1 | 1 | Clearcut | Yes | -- | -- | -- | -- |
| 1 | 2 | Clearcut | No | -- | -- | -- | -- |
| 1 | 3 | Shelterwood | Yes | 31 | 16.9 | 24.3 | 93 |
| 1 | 4 | Shelterwood | No | 31 | 17.7 | 26.2 | 90 |
| 1 | 5 | Seed Tree | No | 18 | 17.7 | 15.9 | 88 |
| 1 | 6 | Seed Tree | Yes | 18 | 17.3 | 15.0 | 88 |
| 2 | 1 | Clearcut | No | -- | -- | -- | -- |
| 2 | 2 | Clearcut | Yes | -- | -- | -- | -- |
| 2 | 3 | Shelterwood | Yes | 35 | 15.8 | 24.3 | 84 |
| 2 | 4 | Shelterwood | No | 33 | 16.3 | 24.4 | 88 |
| 2 | 5 | Seed tree | Yes | 17 | 15.9 | 11.8 | 82 |
| 2 | 6 | Seed tree | No | 18 | 18.3 | 16.7 | 95 |
| 3 | 1 | Seed tree | No | 18 | 14.1 | 9.5 | 83 |
| 3 | 2 | Seed tree | Yes | 18 | 15.6 | 11.8 | 90 |
| 3 | 3 | Shelterwood | No | 45 | 14.1 | 23.9 | 87 |
| 3 | 4 | Shelterwood | Yes | 41 | 14.8 | 25.0 | 90 |
| 3 | 5 | Clearcut | Yes | -- | -- | -- | -- |
| 3 | 6 | Clearcut | No | -- | -- | -- | -- |
| 4 | 1 | Shelterwood | No | 49 | 13.6 | 24.3 | 69 |
| 4 | 2 | Shelterwood | Yes | 64 | 11.9 | 25.0 | 66 |
| 4 | 3 | Clearcut | No | -- | -- | -- | -- |
| 4 | 4 | Clearcut | Yes | -- | -- | -- | -- |
| 4 | 5 | Seed tree | No | 18 | 16.5 | 13.3 | 84 |
| 4 | 6 | Seed tree | Yes | 18 | 15.9 | 12.5 | 84 |
| 5 | 1 | Seed tree | Yes | 18 | 13.3 | 8.6 | 73 |
| 5 | 2 | Seed tree | No | 18 | 16.8 | 14.1 | 81 |
| 5 | 3 | Shelterwood | Yes | 36 | 16.0 | 25.0 | 79 |
| 5 | 4 | Shelterwood | No | 33 | 16.7 | 24.4 | 79 |
| 5 | 5 | Clearcut | No | -- | -- | -- | -- |
| 5 | 6 | Clearcut | Yes | -- | -- | -- | -- |

## RESULTS

At 1 year after harvest, the number of seedlings established per acre ranged from 200 per acre on the seed tree and burn treatment up to 650 per acre on the shelterwood treatment (table 2). Analysis of variance determined that stocking among treatments was not significantly different. However, in terms of adequate stocking, it appears that this first year did not represent a good seed production year. Based on information from Georgia Forestry Commission Seed Orchards, 1983 was a poor year for seed-production, whereas 1984 and 1985 were good seed producing years (Terrell Brooks, pers. commun., June 10, 1986).

Table 2.--Mean number of pine seedlings per acre for each of 3 years after harvest, by treatment

| Treatment | Year | | |
|---|---|---|---|
| | 1984 | 1985 | 1986 |
| | ---Seedings/acre--- | | |
| Clearcut | 400 a | 1,850 c | 1,250 b |
| Clearcut and burn | 400 a | 3,100 c | 2,550 b |
| Shelterwood | 650 a | 5,900 ab | 4,700 b |
| Shelterwood and burn | 550 a | 9,350 a | 10,900 a |
| Seed tree | 550 a | 4,900 bc | 3,900 b |
| Seed tree and burn | 200 a | 6,950 ab | 5,000 b |

Means followed by the same letter are not significantly different at the 0.05 level.

It is, of course, illogical to assume that survival will be 100 percent, due to either prolonged periods of drought or damage caused by cutting and removing the seed trees from the plots. In fact, the best conclusion is that additional seed are needed on all plots in order to attain an adequate stocking. This is no problem and demonstrates one of the advantages of regeneration by natural means because the seed source is still present and has the potential to supply another seed crop.

At 2 years after harvest, the additional seed crop is evident by increases in the number of seedlings present on all treatment plots (table 2). The shelterwood and burn treatment plots had the most seedlings per acre and increased by 8,800 seedlings per acre over the previous year. Plots with clearcut only treatment had 1,850 seedlings per acre and increased by 1,250 seedlings per acre over the preceding year. These seed are presumed to have come in from the adjacent plots, since advance regeneration is essentially ruled out at this time. However, the clearcut treatment does possess the potential to produce an adequately stocked stand if one-third of the seedlings are able to survive. All other treatments show excellent potential for producing adequately stocked stands at this time. It also appears that it is possible, after two seed crops, for the seed trees to be removed. Damage incurred by this removal would serve to reduce the number of seedlings greatly.

It is of interest to note that at 2 years after harvest, all treatment plots that were prescribed burned had more seedlings per acre than those without the burn. This indicates that the seedbed is more receptive after competing vegetation is reduced along with the litter depth (Brender 1973).

At 3 years after harvest, the shelterwood and burn treatment is the only one that achieved a continued increase in number of seedlings per acre. The largest decrease was from the clearcut treatment, with a 32 percent decease in number of seedlings per acre. These clearcut plots continue to supply the fewest number of seedlings per acre, but they still have potential to achieve full stocking if mortality does not exceed 50 percent of the present density. All the other treatment methods appear to have the potential to achieve full stocking. It is anticipated that the lengthy drought of the past summer (1986) as well as the density reduction that follows the seed tree removal will serve to thin the seedlings on the plots. It is also noteworthy that 3 years after harvest, the plots that were prescribed burned still have more seedlings per acre than those that were not burned.

## SUMMARY

At 3 years after harvest, this study shows that all treatments are successful and have potential to establish an adequately stocked stand. The stand will continue to need management in order to insure proper spacing and the best stocking for the site. The removal of the seed trees should be planned for best benefit to each treatment plot and to improve the long term value of the stand.

The study is also considered to be successful in that it serves to benefit the nonindustrial private forest (NIPF) landowner audience for which it was designed and established by being utilized as a demonstration site.

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# Prescribed Fire

Moderator:

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# REGENERATION OF HARDWOOD COPPICE FOLLOWING CLEARCUTTING WITH AND WITHOUT PRESCRIBED FIRE[1]

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ABSTRACT.--Three hardwood stands in the Piedmont and Southern Appalachians of South Carolina and Georgia were clearfelled in the winter of 1982-83. Following harvest, designated study plots were broadcast burned during the fall of 1983. Hardwood coppice regrowth was measured one and two years after burning. Burning significantly increased the total number of basal sprouts for the oak and miscellaneous species group. Poor drying conditions on north-facing slopes resulted in low intensity fires with less effect on sprout origin. Two years following treatment, the number of small stumps (<5 cm) having at least one living basal sprout were greatest on burned plots. Broadcast burning favorably influenced hardwood coppice regrowth by promoting basal sprouting and by encouraging sprouting from small stumps.

## INTRODUCTION

There are approximately 5.5 million acres of upland hardwoods in the mountain and Piedmont regions of South Carolina and Georgia (Bechtold and Phillips 1983; Tansey 1983). In many instances, these stands have undergone multiple highgrades, leaving them understocked with low quality or undesirable species. These past harvesting practices result in stands that are, in many cases, not indicative of the site's capability.

Broadcast burning is increasingly used as a site preparation tool on U.S. Forest Service lands following harvest of these low quality stands. The expense incurred by burning is considerably less than costs associated with other site preparation techniques (Moak et al. 1983). However, few studies have evaluated the silvicultural advantages of burning logging debris on hardwood coppice in the Southern Appalachians and Upper Piedmont. With the cooperation of the U.S. Forest Service, a study was initiated in 1982 to determine effects of broadcast burning of logging slash on hardwood coppice regrowth. Specific objectives of this study were:

1. To determine effects of burning on the number and origin of hardwood sprouts.

2. To determine the influence of aspect on burning effectiveness.

3. To evaluate effects of stump size on sprout production following burning.

[1]Paper presented at the 4th Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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## METHODS

### Study Areas

Study sites were located in three areas where clearcuts in mixed hardwood stands were planned: (1) Clemson University Experimental Forest, Oconee County, South Carolina; (2) Chattahoochee National Forest, Habersham County, Georgia; and (3) Sumter National Forest, Oconee County, South Carolina. Xeric (south) and mesic (north) aspects with similar slope, soil and species composition were selected on each of the three areas. Prior to harvest, predominant species at all locations were scarlet oak (_Quercus coccinea_ Muenchh.), southern red oak (_Q. falcata_ Michx.), white oak (_Q. alba_ L.), chestnut oak (_Q. prinus_ L.), pignut hickory (_Carya glabra_ Mill.), red maple (_Acer rubrum_ L.), sourwood (_Oxydendrum arboreum_ L.), black cherry (_Prunus serotina_ Marsh.), blackgum (_Nyssa sylvatica_ Marsh.), and dogwood (_Cornus florida_ L.).

Slopes ranged from 40 percent on the Clemson site to 60 percent on the Georgia site. Soils on the Piedmont site were clayey in texture while mountain soils were loamy. All soils developed largely from gneiss and schist parent materials and are classified as Typic Hapludults. Elevation at the Clemson location, a Piedmont site, averaged 800 ft while elevations at the Sumter and Georgia locations in the Southern Appalachian mountains were 1500 and 2500 ft, respectively.

### Sampling Procedures

During the fall of 1982, six 0.12 ac rectangular plots were established on both mesic and xeric aspects at each of the three study areas. Prior to harvest, seedlings and root-suckers <4.5 ft tall were tallied on four 1 m wide transects equally spaced along the contour of each plot. Saplings >4.5 ft, but less than 4.5 in DBH, were tallied between alternate transects by species, DBH, and total height. Trees (>4.5 in DBH) were tallied in a 100 percent inventory.

Harvest of merchantable products from the Clemson and Sumter sites occurred between October 1982 and March 1983. Residual trees were chainsaw felled in July 1983. Limited access, steep topography, and lack of markets prevented removal of otherwise merchantable material from the Georgia site. All stems were clearfelled on this site and left in place.

Three plots on each aspect were burned in October 1983 on all areas. Relative humidities during burning ranged from 30-50 percent, winds averaged 5 mph with occasional gusts, temperatures were in the low 80's, and the last significant rain on the areas occurred 7-12 days prior to the burn. Burning was planned for late summer but was delayed because of weather and logistical problems.

The burning technique used was similar for all areas. Back fires were set at the top of the slopes and at the downwind flanks on both north and south aspects. After the back fires had moved downslope a short distance, strip head fires were ignited in succession at 20-30 ft intervals across the slope until the areas were completely burned.

Fuel consisted of hardwood tops, hardwood litter, and green herbaceous material. The fire was primarily carried by cured leaves on felled hardwood tops. Hardwood litter was fairly continuous on all three areas. Although green herbaceous material was moderately distributed on all areas, poor drying conditions prevented it from being a major fuel component on the northern aspects.

White pine seedlings (2-0) were planted during the winter following the burn, which was prescribed to improve plantability of the site. Large quantities of logging debris in the absence of burning make hand planting nearly impossible. Because of the slow early growth of white pine seedlings, results of this phase of the experiment will be reported later.

Numbers of hardwood seedlings and saplings were inventoried 1 and 2 yr after burning. Sampling methods used were the same as pretreatment inventory methods. Trees and saplings which had been cut during the harvest or clearfelling operations were inventoried on four 305 $ft^2$ sample plots located in each corner of all treatment plots. Sprouts from cut stumps were grouped into classes based on origin. Stool sprouts originated from adventitous buds at the cut surface perimeter of the stump. Sprouts from dormant buds located below the cut surface and above the ground line were designated as epicormic sprouts, while basal sprouts originated at or below the ground line. Coppice sprout data were collected one and two growing seasons after the burn.

Data were statistically analyzed as a split plot design, with aspect designated as the major treatment. Burning was considered the minor treatment and was assigned at random to subplots within each major plot. Locations were considered replications. All treatment differences were tested at the 5 percent level of significance.

## RESULTS AND DISCUSSION

One year after treatment coppice sprouts totaled 104,958 and 78,755 stems/ac on the burned and unburned plots, respectively (Table 1). Oaks comprised 23 percent of the total number of stump sprouts on both burned and unburned plots. Seedlings and seedling sprouts were not as numerous. Oaks accounted for 32 and 16 percent of the total number of seedlings and seedling sprouts on the burned and unburned plots, respectively. While it is doubtful that these densities are needed to successfully regenerate the stand, recent symposia and bibliographies have documented the beneficial effects of increased sprouting following burning on wildlife habitat (Harlow and Van Lear 1981, Wood 1980).

Table 1.--Number of Stump Sprouts, Seedlings or Seedling Sprouts (Per Acre) by Species Group One and Two Years Following Burning. Data Shown Are Combined for All Locations.

| | Year 1 | | Year 2 | |
|---|---|---|---|---|
| | Burned | Unburned | Burned | Unburned |
| STUMP SPROUTS | | | | |
| Oaks | 27,851 | 14,176 | 23,626 | 9,092 |
| Misc. spp. | 77,108 | 64,579 | 66,368 | 55,306 |
| Total | 104,959 | 78,755 | 89,994 | 64,398 |
| SEEDLINGS OR SEEDLING SPROUTS | | | | |
| Oaks | 13,673 | 7,515 | 14,361 | 13,605 |
| Misc. spp. | 29,183 | 40,638 | 40,537 | 51,173 |
| Total | 42,856 | 48,153 | 54,898 | 64,778 |

Since burning killed one-year-old sprouts, age of regrowth differed between burned and unburned plots. One year after treatment, sprouts on burned plots would be one year old while sprouts on unburned plots would be two years old. This unavoidable age difference undoubtedly influenced sprout density on burned and unburned plots at time of sampling. However, the influence of age is considered minor in relation to the effect of burning.

The rate of mortality was related to sprout origin. Two years after treatment, basal sprouts on burned plots had declined 12 percent, while sprouts originating higher on the stump had declined 41 percent (Table 2). Early studies (Roth and Sleeth 1939, Keetch 1944) indicated that burning improves sprout origin. They suggested that, by promoting sprouting lower on the stump, the incidence of decay in sprouts would be less on burned areas. Smith (1969) and Watt (1979) reported that the incidence of decay is less on sprouts originating close to the ground, probably

because such wounds are more readily compartmentalized by callus tissue formation (Jensen 1969, Shigo 1979).

Table 2.--Number of Sprouts (Per Acre) by Origin One and Two Years Following Burning. Data Shown Are Combined for All Locations.

| | OAK SPECIES | | | |
|---|---|---|---|---|
| | Year 1 | | Year 2 | |
| | Burned | Unburned | Burned | Unburned |
| Sprout origin | | | | |
| Basal | 26,920 | 10,023 | 23,304 | 8,663 |
| Epicormic | 895 | 4,081 | 179 | 322 |
| Stool | 36 | 72 | 143 | 107 |
| Total | 27,851 | 14,176 | 23,626 | 9,092 |

| | OTHER SPECIES | | | |
|---|---|---|---|---|
| | Year 1 | | Year 2 | |
| | Burned | Unburned | Burned | Unburned |
| Sprout origin | | | | |
| Basal | 67,836 | 41,740 | 60,354 | 41,310 |
| Epicormic | 9,093 | 20,512 | 5,692 | 12,815 |
| Stool | 179 | 2,327 | 322 | 1,181 |
| Total | 77,108 | 64,579 | 66,368 | 55,306 |

Fire promoted sprout formation lower on the stump. One year after burning, 97 percent of all oak sprouts from cut stumps were classified as basal sprouts, whereas only 71 percent were basal sprouts on unburned plots. Similar results were noted on the miscellaneous species group.

The number of epicormic sprouts, an undesirable type of sprout, in the miscellaneous group was less on burned plots one and two years after treatment. The number of epicormic sprouts on burned plots was only 56 percent of that on unburned plots. Although numbers of epicormic sprouts on oak stumps tended to be higher on unburned plots, differences were not significant because of variability among plots.

Auxin translocation by epicormic sprouts probably limits numbers of basal sprouts by inhibition of suppressed buds at or below the root collar. Our data suggest that numbers of basal sprouts on unburned plots for both oak and miscellaneous species were reduced by higher numbers of epicormic sprouts (Table 2). Basal sprouts for the miscellaneous species group were significantly greater on burned plots one and two years following treatment, while oak basal sprouts were significantly greater on burned plots two years following treatment. Waldrop et al. (1985) also noted increased sprouting of hardwood stumps following broadcast burning in eastern Tennessee, while Danielovich et al. (1987) reported increased sprouting in the mountains of South Carolina after broadcast burning.

Although fire increased basal sprouting of oaks on both northerly and southerly aspects, greatest increases occurred on southern aspects (Table 3). Poor drying conditions under clumps of mountain laurel (*Kalmia latifolia* L.) and the more shaded exposure resulted in spotty, low intensity fires on northern aspects. As a result, many regrowth stems were not top-killed. In contrast, southern slopes burned more intensely with greater top-kill and resprouting. Burned plots on southern aspects had about 3.5 times as many basal sprouts as unburned plots one and two years following burning. As opposed to the fall burning conducted in this study, current Forest Service practice is to burn clearcut sites in the summer when better drying conditions prevail on both southern and northern aspects.

Table 3.--Number of Oak Basal Sprouts (Per Acre) by Aspect One and Two Years Following Burning. Data Shown Are Combined for All Locations.

| Aspect | Treatment | Year 1 | Year 2 |
|---|---|---|---|
| North | Unburned | 3,365 | 3,472 |
| North | Burned | 4,260 | 5,298 |
| South | Unburned | 6,658 | 5,191 |
| South | Burned | 22,660 | 18,006 |

The diameter distribution of stumps with at least one living basal sprout is perhaps more important than total numbers of sprouts. Sprouts from smaller diameter stumps are a most desirable form of hardwood regeneration (Sanders 1971). The number of oak stumps (<5 cm) with at least one living basal sprout was significantly greater on burned plots after two years (Table 4). This difference is largely attributed to the fact that burning top-killed small hardwood stems, thereby promoting basal sprouting. On unburned plots, these small stems continued to grow and produced no basal sprouts. Therefore, they were not considered to be small stumps. Regeneration starting over from new sprouts may be more desirable than flat-topped individuals which existed in the understory because of potentially better growth form (Teuke and Van Lear 1983, O'Hara 1986).

Table 4.--Number of Stumps (Per Acre) With at Least One Living Basal Sprout by Diameter Class Two Years Following Burning. Data Shown Are Combined for All Locations.

| | Diameter Class (cm) | | | |
|---|---|---|---|---|
| | <5 | 5-9 | 10-14 | >15 |
| Burned | 1,468 | 608 | 466 | 751 |
| Unburned | 501 | 215 | 287 | 787 |

## CONCLUSIONS

Regeneration by sprouting was prolific on both burned and unburned plots. However, burning improved sprout quality by promoting basal sprouting. Burning increased the total number of basal sprouts for both the oak and miscellaneous species groups. Since basal sprouts are well anchored and tend to resist decay, the effect of burning is considered favorable. While increased sprouting by miscellaneous species following burning will benefit browsing wildlife, these sprouts will probably not be a major component in the upper canopy of the mature stand because of the long-term competitive nature of oaks.

The greatest number of basal sprouts was on burned plots with southerly aspects, indicating the importance of high intensity fires in establishing well-anchored sprouts which can develop free from defect and decay. Fires of the desired intensity on northern aspects may be more readily achieved by burning in the summer rather than in the fall. Numbers of small stumps (<5 cm) having at least one living basal sprout were greater on burned plots two years after treatment. Because small stumps tend to produce a minimum of sprouts and yet give rapid height growth, they provide the most desirable coppice regeneration.

While results of this study indicate that burning improves the origin of hardwood sprouts and may increase numbers of small stumps having at least one basal sprout, the long-term effects of burning on the composition and quality of hardwood stands needs further research.

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Prescribed Burning in Mature Pine-Hardwood Stands--Effects on Hardwoods and Small Mammals[1]

D. L. Sanders, D. H. Van Lear and D. C. Guynn[2]

ABSTRACT.--Winter prescribed fire in mature pine-hardwood stands (60-95 years old) in the Southern Appalachians had little or no adverse effect on large hardwood crop trees. Hardwoods >15.5 inches in diameter exhibited no cambium damage in the first year after burning. Only five percent of hardwood stems between 5.5 and 12 inches in diameter showed short-term evidence of cambium damage from burning, suggesting that low intensity prescribed burning in mature hardwood stands will have minimal impacts on stem quality. The low-intensity fires top-killed hardwoods <2 inches in diameter and encouraged them to sprout. Forbs and grasses did not increase after burning, probably because full stocking of the overstory limited light reaching the forest floor. Trapping studies indicated that mature pine-hardwood stands were poor habitat for small mammals. Their populations were not changed by a single low intensity fire.

## INTRODUCTION

In recent years, winter backing fires of low intensity have been used for wildlife management purposes in mature hardwood and pine-hardwood stands in mountainous terrain of the Sumter National Forest, South Carolina. Whether these low-intensity prescribed burns during the dormant season cause cambium damage to mature crop trees in hardwood stands is uncertain (Van Lear and Johnson 1983). Early studies (Hepting and Hedgecock 1937, Nelson et al. 1933) linked heartrot in hardwoods to basal scarring by fire, but this damage generally followed higher intensity wildfires.

Prescribed burning, primarily in pine stands, has been a major part of wildlife management in the South since the early 1930's (Stoddard 1931). Even though fire is often used as a wildlife management tool, little is known about the effects on small mammals which utilize the forest floor for food, nesting, and hiding cover. This is especially true in mature mixed pine-hardwood stands.

The objectives of this study were: 1) to determine effects of dormant season backing fires in mature pine-hardwood stands on the cambium of larger hardwood stems 2) to measure response of understory vegetation to this type of burning in the Southern Appalachian Mountains and 3) to evaluate effects of these fires on small mammal populations.

[1]Paper presented at the 4th Biennial Southern Silvicultural Research Conference, Atlanta, GA., November 4-6, 1986.

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## STUDY AREA

The study was conducted on the Sumter National Forest in South Carolina. The study area is part of the Appalachian Hardwood subregion of the Southern Hardwood region (Barrett 1980). Normal annual precipitation, based on a 30-year average, is 66 inches. Average daily minimum temperature is 46°F and the average maximum is 70°F.

Soils were predominantly of the Brevard, Chandler, and Evard series and are classified as Typic Hapludults. Slopes ranged from 3 to 30 percent.

## MATERIALS AND METHODS

Effects of low-intensity winter backing fires on cambium damage in hardwood >3 inches in diameter were examined in two mature pine-hardwood stands using a technique modified from Kayll (1963). Two months after burning, two cambium samples were taken from the charred area of the lower bole of six species. Ten trees in each of four diameter classes (3-5.5, 5.6-10.5, 10.6-15.5, and >15.5 inches) were sampled for each species. Diameter was measured at 4.5 ft above ground. For certain species, it was not possible to locate ten trees in the larger diameter classes, so 8 or 9 trees were used. Cambium samples were extracted about 1 ft above the ground using a size 14 leather punch and placed in a 1 percent solution of 2, 3, 5 triphenyl tetrazolium chloride (TTC). Samples were refrigerated 24 to 36 hr, sliced in half, and examined visually. A pink cambium indicated that cells were alive, implying no short-term adverse effect of burning on the cambium. Failure of the sample to turn pink indicated that the cambium cells were dead and implied fire damage to the tree bole.

Stands sampled to determine effects of fire on stem quality of hardwood trees were burned in March using backing fires which moved down slope at a rate of about 1 ft/min. Maximum temperature during burning ranged from 48 to 64°F. Windspeed was 5 mph with a southerly or westerly direction.

Responses of understory vegetation and small mammal populations to low-intensity winter burning were evaluated in two other mature mixed pine-hardwood stands. These were different stands from those used to examine the effect of burning on hardwood stem quality, but were similar in age, composition, and site conditions. This portion of the study was installed in a randomized complete block design on four 1.24 ac plots. In each stand, one plot was randomly selected for burning and the other served as a control. Burning was conducted in February and March using back-firing techniques under conditions similar to those described above. Understory vegetation was sampled on two perpendicular 3.3 by 32.8 ft transects and a circular subplot (radius 16.4 ft) located at each of eight random points on each plot. Preburn biomass of vegetation <2 ft was clipped after counting woody and herbaceous stems from a 3.3 ft radius circle at the center of each subplot. Subsequent tallies and clipping of vegetation were conducted in the 3rd and 4th quarters of the circular subplot. Biomass was estimated just prior to burning and 16 months after burning.

### Small Mammal Sampling

Small mammals were collected using mouse traps and drift fences with pitfalls. Each plot had 28 trap stations. The drift fence was located in the center of each plot and consisted of three 16.4 ft by 20 inch legs of aluminum flashing. At the end of each leg, a 19-quart plastic bucket was installed flush with the ground.

Trapping was conducted four different times. For each trapping period, 84 Victor mouse traps were set on each site (3 traps at each of the 28 stations) and drift fences were opened by removing the lids from the buckets. Traps were baited with peanut butter and buckets were filled with water to drown the animals. The first trapping in February of 1984 was conducted for four consective nights (one night of prebaiting and three nights with traps set and buckets open). The second trapping was conducted after prescribed burning in June of 1984 for six nights. One night of prebaiting was still used, but the number of nights traps and buckets were open was increased to five nights. The third and fourth trappings were also done for six nights and were in late November - early December and June, respectively. During trapping periods, traps were checked once every morning.

The probability of capture, $\hat{p}$, (# animals caught/# traps actually available for capture) was calculated for each treatment during each trapping period. Because these probabilities were so low, no statistical tests were conducted.

## RESULTS AND DISCUSSION

### Cambium damage to hardwood trees

About 20 percent of the sampled hardwood trees 3 to 5.5 inches in diameter showed evidence of cambium damage from the low-intensity winter burn (Table 1). Only 4-5 percent of sampled trees in the 5.6 to 10.5 inch and 10.6 to 15.5 inch diameter classes indicated cambium damage from the fire. Trees in the largest diameter class showed no evidence of cambium damage in the two months after burning. Indications of damage in Table 1 are high because many trees in the stand were not charred and therefore were not sampled.

Table 1. Percentage of sampled hardwood trees exhibiting cambium damage following dormant season backing fires on the Sumter National Forest, South Carolina.

| SPECIES | DIAMETER CLASS (Inches) 3-5.5 | 5.6-10.5 | 10.6-15.5 | 15.6 and above |
|---|---|---|---|---|
| | | -%- | | |
| Red oak | 10 | 0 | 11 | 0 |
| White oak | 27 | 0 | 0 | 0 |
| Hickory | 30 | 11 | 10 | 0 |
| Blackgum | 10 | 0 | 0 | 0 |
| Red maple | 20 | 10 | 0 | 0 |
| Yellow-poplar | 20 | 10 | 0 | 0 |
| Average | 20 | 5 | 4 | 0 |

Four of the six species sampled in the 10.6-15.5 inch diameter class showed no evidence of cambium damage. However, 11 percent of the red oaks in this size category and 10 percent of the hickories indicated some degree of cambium damage. These species would be expected to be more heat tolerant than such species as red maple (Hare 1965). It is possible that difficulties in extracting samples and judging color of cambium samples following soaking in TTC occasionally resulted in a false determination of damage. The data showed that smaller trees are more susceptible to cambium damage during burning, probably because small trees have thinner bark. Hare (1965) found that bark thickness was closely related to the time for the cambium to reach lethal temperatures.

Flame heights for these low-intensity backing fires averaged about 4-6 inches. Fires of this intensity apparently have little, if any, adverse short-term effect on the cambium of large hardwoods (>15.5 inches) and only minor impact (5%) on trees of medium size (5.6-15.5 inches). Most trees of this size would be sold as pulpwood, rather than sawtimber, so tree quality would not be a major consideration.

These data indicate that low-intensity fires can be judiciously used late in the rotation for wildlife habitat improvement in hardwood or mixed pine-hardwood stands under even-age management with little concern for effects on stem quality of crop trees. Damage to small diameter trees late in a rotation is of little consequence, since such trees are not crop trees. When mature even-age stands are harvested, small unmerchantable trees, fire damaged or not, should be felled allowing an even-aged coppice hardwood stand or a mixed orgin pine-hardwood stand to regenerate.

Effects on understory vegetation

Burning top-killed most of the small (<2 inch) hardwood understory stems in the mature pine-hardwood stands. About 98 percent of the fire-damaged small hardwood trees sprouted. Average diameter of the top-killed trees ranged from 0.4 to 1.1 inches (Table 2), indicating that trees greater than about 2 inches in diameter are not likely to be top-killed by similar low-intensity burns. The average number of sprouts per stump ranged from 2 to 8 one year after burning, while the average height of the tallest sprout was from 1 to 5.5 ft. This increase in sprouting is the major wildlife benefit from this type of burning. Many studies have documented the improved palatability and nutrition, as well as better accessibility, of new sprouts following burning.

Density and biomass of woody ground vegetation (≦2 ft tall) tended to increase after the burn, but due to the large variance between plots the increase was not significant (Table 3).

Table 2. Average preburn diameter of top-killed understory hardwoods and the number and height of sprouts following winter burning in mature pine-hardwood stands.

| | AVERAGE PREBURN DIAMETER (in) | AVERAGE # SPROUTS/STUMP | AVERAGE HEIGHT OF TALLEST SPROUT (ft) |
|---|---|---|---|
| Red maple | 0.59 | 8 | 5.6 |
| Red oak | 0.94 | 3 | 1.3 |
| Sourwood | 0.67 | 5 | 2.6 |
| White oak | 0.63 | 5 | 2.0 |
| Yellow-poplar | 0.75 | 4 | 3.0 |
| Black cherry | 1.10 | 8 | 5.8 |
| Black gum | 0.51 | 3 | 2.0 |
| Dogwood | 0.75 | 6 | 1.0 |
| Hawthorn | 0.39 | 6 | 1.0 |
| Horse sugar | 0.87 | 7 | 3.3 |

Table 3. Woody vegetation (<2 ft tall) density and biomass on burned and unburned plots in mature pine-hardwood stands on the Sumter National Forest in South Carolina.

| TIME | BURNED | | CONTROL | |
|---|---|---|---|---|
| | DENSITY | BIOMASS | DENSITY | BIOMASS |
| | stems/ac | lbs/ac | stems/ac | lbs/ac |
| Before Burning | 117,915 | 50 | 145,749 | 51 |
| 1 Year After Burning | 225,202 | 61 | 153,846 | 38 |

Biomass of forbs and grasses did not increase after burning because full overstory stocking limited light reaching the forest floor.

Small mammals

Few small mammals were caught on either burned or unburned plots in the year following treatment (Table 4). Three families and six species were caught on the burned plots. Only twelve individuals were captured on burned plots, with the white-footed mouse, deer mouse, and the pygmy shrew making up 75 percent of the total. Only two families and two species were caught on the control plots with northern short-tailed shrew and southeastern shrew comprising 75 percent of the eight individuals captured. The pygmy shrew, caught twice on a burned site, had never been recorded in South Carolina.

Small mammals, such as moles, mice, shrews, and ground squirrels are important members of the forest ecosystem (Dueser and Shugart 1978), but little is known about their population densities in upland hardwood stands of the Southeast. Numbers of small mammals captured in this study were too small for statistical analysis. Pearson (1959) and Atkeson (1974) found the relative abundance of small mammals changed with the types and amounts of vegetative cover. When successional stages advance, small mammal diversity and abundance decrease, and only a few species benefit in developing older forests. The study area contained few seed-bearing grasses and forbs found in younger open stands which are necessary for small mammals to thrive. Because of lack of desirable vegetation for food and cover, small mammal populations were sparse on the study sites both before and after burning.

## CONCLUSIONS

Winter burning using low-intensity backing fires caused no cambium damage to large (>15 inch) stems in mature hardwood stands. Medium-sized (5.6-15.5 inches) hardwood trees also exhibited little cambium damage. Based on these results, we conclude that winter backing fires under weather and fuel conditions similar to those in this study can be effectively used in mature pine-hardwood stands to improve wildlife habitat for certain species without fear of excessively damaging larger hardwood trees. Fire damage to smaller trees is of little consequence with regard to timber production in even-age management systems following harvest. All residual trees should be clearfelled because sprouts from stumps and advance regeneration have better growth potential than small residual trees (O'Hara 1986).

Top-kill or damage to small (<2 inches) hardwoods encourages sprouting which benefits large browsing wildlife species such as deer. However, mature hardwood stands in the southern Appalachian Mountains are poor habitat for small mammals. The low-intensity prescribed burning was not hot enough to alter the habitat variables, e.g., seed production by herbaceous plants, important to many small mammals. Burning in mature mixed pine-hardwood stands could not be

considered beneficial or harmful to small mammals, but certainly would benefit other wildlife species which thrive on new sprout growth.

Table 4. Number of small mammals captured on pine-hardwood sites on the Sumter National Forest, South Carolina (1984-85).

| FAMILY/SPECIES | BURN | CONTROL | TOTAL |
|---|---|---|---|
| Cricetidae | | | |
| White-footed Mouse | 5 | -- | 5 |
| Deer Mouse | 2 | 1 | 3 |
| Golden Mouse | -- | -- | 0 |
| Woodland Vole | -- | -- | 0 |
| Zapodidae | | | |
| Meadow Jumping Mouse | 1 | -- | 1 |
| Soricidae | | | |
| Northern Short-tail Shrew | 1 | 2 | 3 |
| Southeastern Shrew | -- | 4 | 4 |
| Smokey Shrew | -- | 1 | 1 |
| Pygmy Shrew | 2 | -- | 2 |
| Least Shrew | 1 | -- | 1 |
| Total No. of Individuals | 12 | 8 | 20 |

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PRESCRIBED FIRE FOR PRECOMMERCIAL THINNING IN A FOUR-YEAR-OLD LOBLOLLY PINE STAND[1]

Thomas A. Waldrop and F. Thomas Lloyd[2]

Abstract.--A two-phase study was conducted to determine the feasibility of using prescribed fire to thin young, naturally regenerated loblolly pine stands. In Phase I, survival after winter backing, strip head, flanking, and spot fires was compared. Backing fires were chosen for Phase II on the basis of survival of the largest trees and uniformity of thinning. In Phase II, burning produced the effect of a thinning from below and reduced density from 6,800 to 2,850 stems per acre (58 percent). Crown scorch was heavy but needle consumption was infrequent. Much of the study area remained overstocked with few spots being understocked. Diameter growth of surviving trees was unaffected but height growth was reduced by 33 percent. Precommercial thinning of dense natural stands with fire shows promise but needs additional study before general recommendations can be made.

Keywords: crown scorch, needle consumption, South Carolina, nearest neighbor.

## INTRODUCTION

Coastal Plain stands of loblolly pine (Pinus taeda L.) are often regenerated by natural means, whether by design or by accident. Since large seed crops are produced almost every year in this region (Langdon 1981), young stands are usually dense. On the Francis Marion National Forest, approximately 1000 acres of such stands are hand-thinned annually at a cost of $55 per acre.[3] Prescribed burning could be a less expensive method of precommercial thinning that would provide the additional benefit of protecting stands from wildfire at a younger age than is currently practiced.

Even though prescribed fire is generally not recommended for sapling-sized stands, its feasibility for precommercial thinning has been studied for several species. The first studies were with uneven-aged Ponderosa pine (P. ponderosa Laws.) stands (Weaver 1947; Morris and Mowat 1958; and Wooldredge and Weaver 1965). Because some areas were too heavily thinned while others were not thinned enough and height growth was reduced, a summary task force on fire in the Northern Rocky Mountains (Roe and others 1971) did not recommend prescribed burning for precommercial thinning in western pines. Muraro (1977) concluded that prescribed burning should not be conducted in lodgepole pine (P. contorta Dougl.) stands younger than 25- to 30-years-old due to a lack of surface fuels and susceptibility to Ips beetle attack.

In the South, precommercial thinning with fire was recommended by McNab (1977) for loblolly pine stands and Nickles and others (1981) for shortleaf pine (P. echinata Mill.) stands with a large range of tree sizes. In both studies, burning acted as a thinning from below with high mortality only in the smallest size classes. A high negative correlation existed between mortality rates and bark thickness at the root collar.

For prescribed burning to be a successful tool for thinning young pines, data is needed to describe how various burning techniques affect survival, growth, and spacing of stands over a wide range of conditions. This paper describes the results of a two-phase study of the feasiblilty of using prescribed fire to thin young, naturally regenerated loblolly pine stands. The first phase compared four burning techniques and selected the best on the basis of survival of largest trees and uniformity of thinning. The burning technique selected in the first phase was used in the second phase to study survival, growth, and uniformity of stocking.

[1] Paper presented to the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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STUDY AREA

The study is located on the Santee Experimental Forest in Berkeley County, South Carolina at an elevation of approximately 25 feet above mean sea level. Soils are Aeric Ochraquults of the Wahee series and are somewhat poorly drained and slowly permeable. Slopes range from 0 to 4 percent. Site index for loblolly pine at age 50 is 86 feet.

At the time of study establishment (Winter 1986), the stand was 4-years-old consisting almost entirely of loblolly pine saplings resulting from seeding from adjacent stands. Diameters at breast height ranged from less than 0.5 inch to 2.6 inches with a mean of 0.6 inch. Tree heights ranged from less than 5 feet to 15.6 feet with a mean of 7.3 feet. Stocking was at aproximately 6,800 stems per acre.

The previous stand was clearcut in November 1981 after a winter prescribed burn and 3 annual summer burns. Logging slash was burned the following March. The area was then planted with loblolly pine seedlings on an 8 by 12 foot spacing. However, survival of planted seedlings was less than 20 percent due to an infestation of Pales weevil. After planting, the area was fertilized with 250 pounds per acre of 0-46-0 triple superphosphate.

PHASE I

Test of Burning Techniques

Four burning techniques were tested to determine the most feasible for thinning a sapling-sized stand. Each of four study plots, 130 by 60 feet in size, was burned by either a backing fire, strip headfire, flanking fire, or a spot fire with a 6 by 6 foot spacing between spots. Burns were conducted on January 17, 1986, 6 days after a rainfall of 0.56 inch. Burning began at 12:00 pm with a temperature of 70 degrees F. and a relative humidity of 42 percent. Winds were from the southeast at a speed of 4 to 7 miles per hour. Surface fuels were light on all plots. However, dried broomsedge (Andropogon virginicus L.) covered most of the area and carried the fires.

A strip headfire was conducted by setting a backing fire followed by strips at 5 to 8 foot intervals. Flame heights remained at 2 to 3 feet except where strips came together and flames overtopped some trees. This variability in fire intensity was intentional to kill some trees while leaving others.

The backing fire traveled into the wind at a rate of 1.5 feet per minute. Flame heights remained uniform at 1 to 2 feet with no evidence of flames reaching the lowest tree limbs. The backing fire was intended to girdle the stems of small diameter trees while leaving larger trees alive.

The flanking fire began with a backing fire perpendicular to the wind, followed by several flanks aproximately 15 feet long set parallel to the wind. Resulting flames were variable in height, ranging from 1 foot or less where flanks backed into the wind to levels above treetops where flanks came together. As with a strip headfire the variable fire intensity was intentional to kill only a portion of the stand.

The spot fire was started first with a backing fire, then spots were set on a 6 by 6 foot spacing while moving into the wind. The method was intended to cover the plot with fire quickly while putting spots close enough to prevent flames of high intensity. However, this method produced a high intensity fire over the entire plot with flames overtopping most trees. Therefore, this method was not considered feasable for precommercial thinning in such young stands and was not included in subsequent measurements.

An estimate of survival was conducted 2 weeks after burning in plots where backing, strip headfire, and flanking fires were used. A random sample of 100 trees was selected in each plot and the cambium of each tree observed. Trees were assumed to be dead or dying if more than 50 percent of the circumference of the cambium at ground level was brown. Each tree was tallied as alive or dead and total height was measured.

Results

Mortality by height class is compared for three burning techniques in Figure 1. For all burning techniques, mortality was high in the two smallest size classes (less than 9 feet and 9 to 12 feet) and relatively low among the largest trees (over 12 feet), thus producing the effect of a thinning from below. Among the largest trees, survival was highest with the backing fire (68.7 percent) as compared to the flanking fire (50 percent) and strip headfire (57.1 percent). Since the flanking and strip headfires produced variable fire intensities, some spots were too heavily thinned while others were not thinned enough. Thinning was most uniform over the entire plot with the backing fire. Therefore, backing fires were selected for use in Phase II of this study.

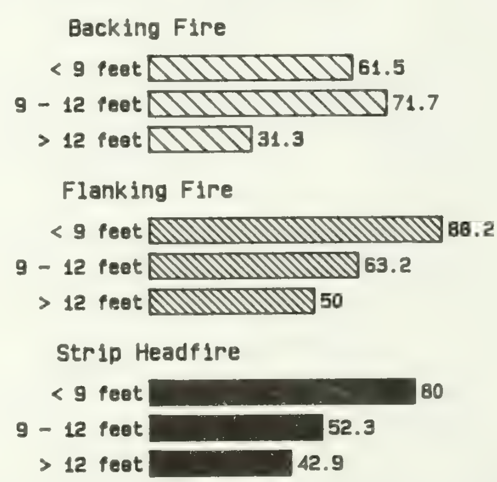


Figure 1.--Percent mortality by height class two weeks after winter prescribed fires of various techniques.

## PHASE II

### Study Design

The study was established as a split-plot randomized complete block design with five replications, two whole plots per replication, and two subplots per whole plot. Whole plots were 131 feet square (0.4 acre) and assigned to blocks on the basis of having similar pretreatment stocking and size distributions. Each plot within a replication was randomly selected to be burned or left as an unburned control. Whole plots were split into fertilized and unfertilized subplots to observe the interaction of burning with fertilization, which should accelerate the growth of dominant trees. Fertilized subplots received triple superphosphate and urea at levels of 25 pounds P and 200 pounds N per acre.

### Burning Conditions

Backing fires were conducted on February 3, 1986, 4 days after a rain of 0.42 inch and 7 days after a rain of 0.91 inch. Burning began at approximately 12:30 pm with a temperature of 70 degrees F. and a relative humidity of 38 percent. Winds were from the southwest at 3 to 5 miles per hour. Fuels along the ground were light and moist but the entire study area was covered with dried broomsedge which carried the fires. Flames were generally 1 to 3 feet in height (6 to 26 Btu/second/foot using Byrams flame length index, Brown and Davis 1973). Occasionally, flames reached 4 to 5 feet in height (116 to 188 Btu/second/foot) where vertical fuels (broomsedge and needle drape) were heavy. The mean rate of spread over all replications was 3 feet per minute. Burning was concluded at approximately 1:30 pm.

### Measurements

Measurements were taken in each of the five replications to examine the degree of crown scorch and needle consumption resulting from backing fires, survival by size class, uniformity of stocking before and after burning, and growth of survivors in burned and control plots. In May 1986, 3 months after burning, degree of crown scorch and needle consumption were estimated for every tree over five feet tall on a 0.04 acre sample plot in each of the 10 burned subplots. For each tree, the height to the bottom of the crown, highest point of needle consumption, highest node with scorched needles, total height, and dbh was measured. Crown scorch and needle consumption were expressed as a percentage of the length of the crown before burning. Each tree was tallied as alive or dead to compare size distributions before and after burning and to relate mortality to degree of crown damage.

Stocking levels before and after burning were estimated at 54 randomly selected points throughout each burned plot to examine uniformity of thinning. The nearest neighbor technique (Clark and Evans 1954) was used by measuring the point to the nearest tree (either alive or dead) and to the nearest live tree. Measured distances were converted to point estimates of density by the method of Thompson (1956). Measurement of distance to the nearest tree and the nearest live tree allowed a comparison of densities before and after burning.

The effect of burning on tree growth was studied by comparing dbh and height growth between burned and control plots. In each 0.04 acre sample plot, both in fertilized and unfertilized subplots, the dbh and height of each of 40 trees was measured at the beginning and end of the 1986 growing season. Sample trees were selected as the largest on each sample plot since those would be most likely to survive the burning treatment and reach rotation age. Mean subplot dbh and height growth were compared by analysis of variance.

## RESULTS AND DISCUSSION

### Mortality and Size Distribution

Prescribed burning reduced the total number of stems per acre from 6,800 to 2,850 (58 percent). The highest mortality rates were in the lower diameter (Figure 2) and height (Figure 3) classes. Mortality was 88 percent and 53 percent in the 0.2 inch and 0.6 inch diameter classes, respectively. The 6 foot height class had 80 percent mortality while the 8 foot class had 47 percent. Mortality in the upper dbh and height classes was near zero.

The pattern of thinning was silviculturally desirable, resembling a thinning from below. Burning changed the diameter and height distribution from a reverse-J pattern, with large numbers of small trees, to a bell-shaped pattern with medium-sized trees being most frequent (Figures 2 and 3). As a result, mean tree dbh increased from 0.6 inch to 0.9 inch and mean tree height increased from 7.3 feet to 8.4 feet. Even though burning substantially reduced the total number of stems, the stand was still dense. A burn of somewhat higher intensity may kill more trees in the small size classes, thus better improving growing conditions for the larger survivors. These results closely resemble those of McNab (1977) in a much older (17.5 years) loblolly pine stand.

### Crown Damage and Mortality

Crown damage due to backing fires was heavy in all study plots. Over 5,500 trees per acre (81 percent) recieved at least 40 percent crown scorch while over 4,200 trees per acre (62 percent) were totally scorched. Even though crown scorch was heavy, the incidence of needle consumption was low. Only 26 percent of all trees showed evidence of needle consumption.

Several studies have shown mortality of pole-sized or larger pines with severe crown scorch (Storey and Merkel 1960; Methven 1971; Villarrubia and Chambers 1978; and Waldrop and Van Lear 1984). When working with trees generally less than 20 feet tall, Wade (1985) found that degree of needle consumption was a better predictor of mortality than crown scorch. He showed that survival was

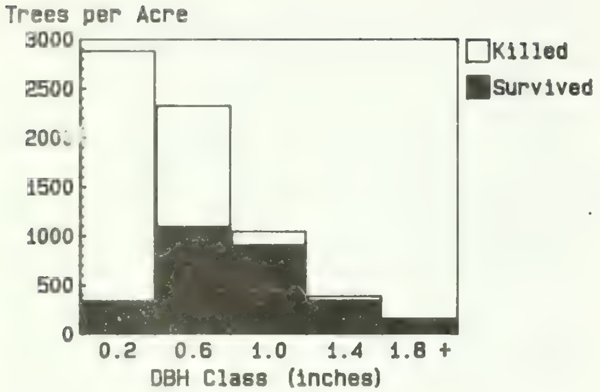


Figure 2.--Change in diameter (dbh) distribution of a 4-year-old loblolly pine stand after a winter backing fire.

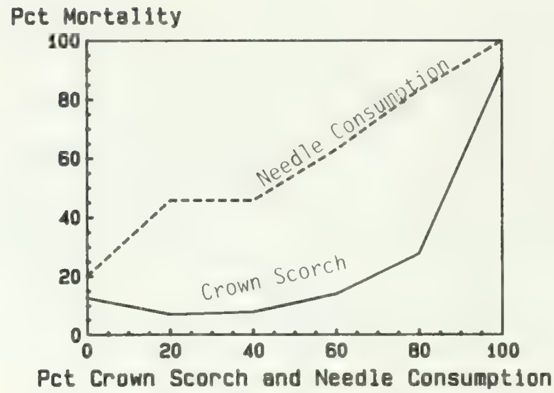


Figure 4.--Percent mortality by percent crown scorch and needle consumption after a winter backing fire.

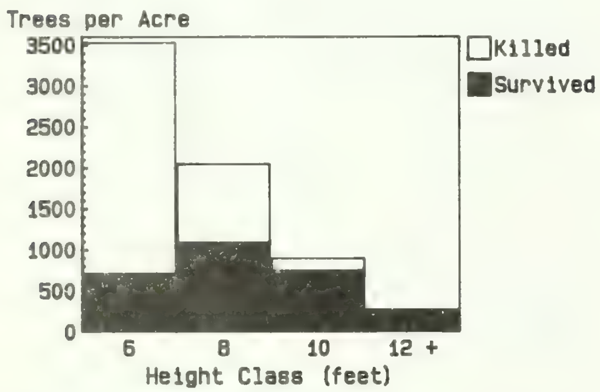


Figure 3.--Change in height distribution of a 4-year-old loblolly pine stand after a winter backing fire.

less than 50 percent among trees with 20 percent needle consumption or more. Figure 4 shows the rate of mortality of trees with various degrees of crown scorch and needle consumption in this study. Mortality was low among trees with less than 80 percent crown scorch. Above the 80 percent crown scorch level, mortality becomes very high. Similar to Wade's findings, mortality was over 50 percent when needle consumption was 20 percent or more.

Mortality occurred even at low levels of crown scorch (Figure 4), indicating that crown damage may not be the only cause of mortality. McNab (1977) and Nickles et al. (1981) found a strong correlation between survival and bark thickness at the root collar, suggesting that mortality was caused by stem damage. Although not conclusive, these data suggest that mortality after a backing fire in a sapling-sized stand may be caused by both crown and stem damage.

Uniformity of Stocking

The percentage of the total study area stocked at various levels before and after burning is shown in Table 1. Before burning, the majority (80.1 percent) of the study area was overstocked. For the purpose of this paper, overstocked is defined as 1600 stems per acre or more. After burning, the majority of the area (54.3 percent) was stocked at levels of 400 to 1,200 stems per acre, which are acceptable for many forest products. The remaining 45.7 percent of the area was still overstocked with densities as high as 12,000 stems per acre, yielding a mean of 2,850 stems per acre. However, a single prescribed backing fire effectively lowered stocking levels over the entire study area. In addition, areas that were understocked (fewer than 400 stems per acre) were essentially absent. The absence of understocked areas indicates that backing fires are preferable to flanking and strip headfires where hot spots and, therefore, areas of high mortality are more frequent.

Table 1.--Percentage of the total study area stocked at various densities before and after burning.

| Stems per Acre | Before Burning | After Burning |
|---|---|---|
| | (Pct) | (Pct) |
| 400 | 3.5 | 27.9 |
| 800 | 10.0 | 17.1 |
| 1200 | 6.5 | 9.3 |
| 1600+ | 80.0 | 45.7 |
| Total | 100 | 100 |

## Tree Growth

When crown damage from burning is high, as with this study, pine growth is often reduced (Johansen 1975 and 1984; McCulley 1950). Johansen and Wade (1985) reported the loss of an entire year's diameter growth in trees with severe crown scorch. In this study, an analysis of variance showed no significant differences in mean diameter growth of sampled trees in burned and unburned study plots, regardless of whether they had been fertilized (Table 2). Fertilization significantly increased diameter growth on burned and unburned plots.

Table 2.--Diameter (dbh) and height growth one growing season after a winter backing fire.

| Treatment | DBH Growth (in) | Height Growth (feet) |
|---|---|---|
| Burned - No Fertilizer | 0.31 a[1] | 1.8a |
| Unburned - No Fertilizer | 0.37 a | 2.7 b |
| Burned - Fertilized | 0.47 b | 2.0a |
| Unburned - Fertilized | 0.48 b | 2.6 b |

[1] Means followed by the same letter within a column are not significantly different at the 5 percent level.

Height growth of sample trees was adversely affected by a single winter backing fire (Table 2). In plots that were not fertilized, height growth averaged 2.7 feet in unburned controls the year after burning as compared to only 1.8 feet in burned plots. Fertilization had no affect on height growth which is consistant with the findings of McKee and others (1986).

Since burning reduced height growth but not diameter growth, it is assumed that in highly scorched trees carbohydrates stored over winter were used for needle production and some diameter growth, rather than stem elongation. Therefore, height growth may have been minimal during the first flush of buds and trees in burned plots lagged behind those in control plots. A close comparison of the number of flushes and the stem length between flushes of trees in burned and control plots would give better insight into the effect burning had on height growth.

Even though some height growth was lost the year after burning, the loss was less than expected. In unfertilized plots, height growth was reduced by 33 percent in burned plots as compared to controls. In addition, competition among trees will be grealty reduced. Therefore, growth rates of individual trees can be expected to be greater in burned plots than in controls during future years. Close monitoring of tree growth and stand dynamics in these study plots over the next few years will provide a longer-term evaluation of prescribed fire for precommercial thinning.

## SUMMARY AND CONCLUSIONS

A comparison of backing, flanking, spot, and strip headfires showed that each acted as a thinning from below with high mortality in small tree size classes. Backing fires provided the highest survival rates among the largest trees and the most uniform thinning throughout the study plot. Therefore, backing fires were chosen for continued study in this natural 4-year-old loblolly pine stand.

A winter backing fire reduced the number of stems per acre from 6,800 to 2,850. The pattern of thinning was silviculturally desirable since the diameter and height size distribution was changed from a reverse-J to a bell-shaped pattern. Also, mean tree height and diameter were increased. Crown scorch was high throughout burned plots but needle consumption was infrequent. Mortality was most common among trees with at least 80 percent crown scorch and/or some degree of needle consumption. Burning improved the uniformity of stocking since understocked areas were esentially absent and overstocked areas were less frequent than before burning. However, almost half of the area remained overstocked. Diameter growth during the year after burning was not affected but height growth was reduced by 33 percent (2.7 feet in control plots vs. 1.8 feet in burned plots).

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# AN INSIGHT INTO THINNING YOUNG SLASH PINE STANDS WITH FIRE[1]

R. W. Johansen and D. D. Wade[2]

Abstract.--Unwanted young slash pines can be eliminated from a stand with a prescribed fire if burning takes place before the basal stem diameters (6 inches above ground level) of target stems reach 1.2 inches. This conclusion is predicated on flame heights always exceeding 6 inches as the fires progress through a stand.

Despite the best efforts of silviculturists, young pine stands are often too dense. Favorable weather and a large seed crop lead to overly dense stands produced by seed-tree, shelterwood, and seed-in-place systems. Volunteers from blown seed lead to overcrowding of plantations.

Precommercial thinning is expensive, but may be necessary to avoid stagnation. Judicious use of prescribed fire often might get the job done at a low cost. Before it can be used, however, foresters need to know what conditions are needed to kill some trees without seriously injuring others. Variables to be considered are stem size, fireline intensity, and fire residence time. Some very useful experience with fire thinning was gained in the study described here.

## METHODS

Two 8-year-old slash pine (Pinus Elliottii Engelm. var elliottii) plantations were chosen for burning during the winter of 1985-86 on the Dixon Memorial State Forest near Waycross, Georgia. These stands had, in addition to the planted trees, numerous volunteers that had seeded in from nearby stands.

The first stand, on Melton Road, was planted on beds 10 feet apart at a 6 foot spacing (726 trees/acre). Volunteers increased stocking more than tenfold in places. In fact, the stand was so dense that crown closure was complete in most places, and pine needle litter was the primary fuel on the forest floor. The planted trees averaged 3.0 inches d.b.h., but ranged from 1.3 to 4.3 inches. The volunteers were all younger and ranged from 2 feet in height to 2.4 inches d.b.h. A backfire was ignited on March 6, 1986 at 10:00 am, and the lead flames reached the other end of the plot at 11:36 am (fire traveled 142 feet). During the burn, the ambient temperature remained at 57° F., and the relative humidity (RH) was 62 percent. Mean flame height was 1.5 feet. The mean fuel weight consumed during the burn was 3.0 tons per acre.

The second plantation, also planted at 6- x 10-foot spacing, bordering on Cowhouse Road had numerous volunteers seeded in from an older, neighboring stand that has since been cut. In a few small areas the volunteer tree density exceeded 10,000 trees per acre, but the population was much less in most of the stand. Available fuel was mainly a thick stand of broomsedge (Andropogon virginicus L. var glaucopsis (Elliott) Hitche.). An average of 2.2 tons of fuel per acre were consumed in burning. Two 1.5 acre burns took place between 2:00 and 5:00 pm on March 6, 1986. When the first plot was ignited at 2:00 pm, the ambient temperature was 57° F., and the RH was 41 percent. By the time the second plot was ignited at 4:00 pm, the ambient temperature had increased to 72° F., and the RH was 32 percent. Mean flame height exceeded 3 feet.

One week after the burns, each plantation was revisited to select and tag trees for later observation of tree survival and growth. Selected trees were numbered and tagged, and then d.b.h. (if they were tall enough) and diameter of the main stem at a point 6 inches above ground level were measured and recorded. This point on the stem was well within the flame envelope during the fire passage and was thought to be representative of the stem portion where heat girdling, if it occurred, would take place. In addition, the fraction of needles scorched (heat killed) by the fire was recorded as well as the fraction of live needles actually consumed by the flames. Fire damage to the tree crown is more easily assessed 1 week after the burn because the heat-killed needles have turned brown but have not yet abscised from the branch.

On July 2, 1986, about 4 months after the burn, each tagged tree in both plantations was visited, and its condition was noted.

[1] Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2] Research Forester and Project Leader, respectively, Southeastern Forest Experiment Station, Southern Forest Fire Laboratory, Dry Branch, GA 31020.

To derive a measure of the resistance of young pine stems to heat girdling from fire, we had to eliminate the possible confounding effect of heat damage to the crowns which could also kill the tree. The high temperatures required to cause consumption of green needles will also frequently cause the death of a tree by heat girdling the upper stems and branches. Therefore, trees exhibiting any amount of needle consumption were not used in this analysis. Crown scorching, however, was disregarded because this type of damage during winter burns in southern pines has been shown to be nonlethal, though it can drastically reduce subsequent stem diameter growth (Wade and Johansen 1986). We also limited the analysis to trees having a stem diameter under 2.41 inches because no larger trees showed any signs of impending mortality.

## RESULTS

Tree responses to fire in both areas were similar. Some 257 trees at Melton Road and 255 trees at Cowhouse Road were included in the mortality analysis. The backing fire in the Melton Road plantation had an average spread rate of 1.5 feet per minute with only slight variation. Fireline intensity, I, a measure of heat output per unit length of fire front, averaged 20 Btu/ft-sec limit usually recommended for backing fires in southern, natural fuels.

Under the fuel and ambient temperature conditions at the Melton site, sufficient heat was developed to girdle the stem and kill 122 of the 130 trees (94 percent) 1 inch or less in stem diameter. As basal diameter increased above 1.00 inch, a decreasing proportion of trees was killed until a tree girth of 1.50 inches was reached, above which no trees were killed (Table 1).

Table 1. Mortality among Melton Road volunteer slash pines in an 8-year-old slash pine plantation 4 months after backfiring in early March.[1] No tallied trees had crown consumption.

| Basal[2] diameter | Trees: Dead | Trees: Total Measured | Mortality |
|---|---|---|---|
| Inches | Number | Number | Percent |
| .11-.20 | 1 | 1 | 100 |
| .21-.30 | 12 | 13 | 92 |
| .31-.40 | 10 | 10 | 100 |
| .41-.50 | 18 | 18 | 100 |
| .51-.60 | 17 | 17 | 100 |
| .61-.70 | 20 | 20 | 100 |
| .71-.80 | 20 | 21 | 95 |
| .81-.90 | 12 | 14 | 86 |
| .91-1.00 | 12 | 16 | 75 |
| 1.01-1.10 | 10 | 14 | 71 |
| 1.11-1.20 | 14 | 20 | 70 |
| 1.21-1.30 | 1 | 17 | 6 |
| 1.31-1.40 | 3 | 8 | 38 |
| 1.41-1.50 | 1 | 12 | 8 |
| 1.51-1.60 | | 7 | 0 |
| 1.61-1.70 | | 11 | 0 |
| 1.71-1.80 | | 10 | 0 |
| 1.81-1.90 | | 7 | 0 |
| 1.91-2.00 | | 7 | 0 |
| 2.01-2.10 | | 7 | 0 |
| 2.11-2.20 | | 2 | 0 |
| 2.21-2.30 | | 0 | 0 |
| 2.31-2.40 | | 5 | 0 |
| All diameters | 151 | 257 | |

[1]Available fuel = 3.0 T/AC; mean fireline intensity (I) = 20.4 Btu/ft-sec, range I = 17.2 - 29.0.
[2]At 6 inches above ground line.

The backing fire rate of spread in the grass fuel of Cowhouse Road plantation averaged 4.2 feet per minute (ranging between 3.0 and 5.0 feet per minute). The mean fireline intensity was 40 Btu/ft-sec, even though fuel loading was less here than at Melton Road. The difference was due to the fire spread rate in this grass fuel being over twice as fast as in the pine needles at Melton Road. Here too about 95 percent of the stems less than 1 inch in diameter 6 inches above ground line were killed. When stem diameter exceeded 1.80 inches, 79 of the 82 sample trees (96 percent) survived (Table 2).

## DISCUSSION

The behavior of woodland fires can be expressed in several ways, but care must be exercised to choose the correct fire parameter if some particular fire effect on vegetation is desired. If some measure of heat input into the tree crowns is desired, Byram's fireline intensity (I=Hwr) would normally be used because "I" is affected not only by "H", heat yield per pound of fuel, but also by "w", the amount of fuel per unit area, and "r", the rate of fire spread. Thus, for a given site, the faster the fire spreads (increasing "r") the higher "I" will be. If "I" is increased, so is flame length, and the heat effect will extend higher into the crown. The parameter "I" does not, however, reflect what happens within the flame envelope near the ground.

The amount of heat to which the lower stem of a tree would be exposed if it is in the flame zone is dependent upon the duration of exposure, known also as residence time. Flame temperature remains relatively constant regardless of flame depth or height. Duration of exposure is determined by the fuel continuity, fuel particle sizes, and fuel arrangement (loose to compact).

Residence time in a particular fuel type should fall within rather narrow limits. The pine needle fuel bed at Melton Road provided an average residence time of approximately 10 seconds. This value can be observed directly or it can be determined from the fire spread rate and the horizontal depth of the flaming zone. Residence time for the Andropogon grass fire on Cowhouse Road was also about 10 seconds.

Table 2. Mortality among Cowhouse Road volunteer slash pines in an 8-year-old slash pine plantation 4 months after backfiring in early March.[1] No tallied trees had crown consumption.

| Basal[2] diameter | Trees: Dead | Trees: Total Measured | Mortality |
|---|---|---|---|
| Inches | Number | Number | Percent |
| .11-.20 | 3 | 3 | 100 |
| .21-.30 | 2 | 2 | 100 |
| .31-.40 | 6 | 6 | 100 |
| .41-.50 | 3 | 3 | 100 |
| .51-.60 | 10 | 10 | 100 |
| .61-.70 | 9 | 9 | 100 |
| .71-.80 | 8 | 8 | 100 |
| .81-.90 | 9 | 10 | 90 |
| .91-1.00 | 15 | 16 | 94 |
| 1.01-1.10 | 12 | 15 | 80 |
| 1.11-1.20 | 9 | 11 | 82 |
| 1.21-1.30 | 12 | 18 | 67 |
| 1.31-1.40 | 11 | 14 | 79 |
| 1.41-1.50 | 3 | 7 | 43 |
| 1.51-1.60 | 6 | 13 | 46 |
| 1.61-1.70 | 5 | 18 | 28 |
| 1.71-1.80 | 4 | 10 | 40 |
| 1.81-1.90 | 2 | 16 | 12 |
| 1.91-2.00 | | 18 | 0 |
| 2.01-2.10 | | 11 | 0 |
| 2.11-2.20 | 1 | 16 | 6 |
| 2.21-2.30 | | 10 | 0 |
| 2.31-2.40 | | 11 | 0 |
| | 130 | 255 | |
| All diameters | | | |

[1]Available fuel = 2.2 T/AC; mean fireline intensity (I) = 40.0 Btu/ft-sec, range I = 30.3 - 50.5.
[2]At 6 inches above ground line.

These data have provided insight into effects of fire in overstocked, young pine stands. With minimum flame heights of 12 inches, we can expect to kill almost all pine trees with a basal diameter of 1 inch or less (6 inches above ground level) when the outside ambient temperature is 55 to 75° F. The trees we desire to save should be at least 2 inches in diameter near the ground. When ambient temperatures are lower at burn time, the "kill diameter" would probably be somewhat less, and when temperatures are higher as on a summer day, trees somewhat larger should be killed. The killing of slightly larger sized saplings at Cowhouse Road was probably because the ambient temperature was 15° F. higher than at the Melton Road burn.

These preliminary results highlight the need to make a decision about use of fire for thinning early in a stand's development. A pine stem not much over 1 inch in daimeter is all that is likely to be affected. By the time the undesirable stems reach 2 inches in diameter, a means of elimination other than fire should be contemplated.

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Wade, Dale D. and R. W. Johansen. 1986. Effects of fire on southern pine: observations and recommendations. USDA For. Serv. Gen. Tech. Rpt. SE-41. Southeast. For. Exp. Stn., Asheville, NC. 14p.

# RELATING WILDLAND FIRE TO DEFOLIATION AND MORTALITY IN PINE[1]

Dale D. Wade and R. W. Johansen[2]

ABSTRACT.--Numerous accounts in the literature demonstrate that the effects of fire on North American pines are highly variable. In some cases trees with severe crown scorch survive and grow more rapidly, while in other cases extensive mortality results. Three of the most important factors affecting a tree's response to fire are the timing of defoliation, level of defoliation, and species differences in bud development. An ongoing field study designed to assess the importance of defoliation level and timing upon southern pine survival and growth is described.

## INTRODUCTION

The literature contains numerous accounts of fire and its effects on the pine forests of North America. This extensive data base spans a period of more than 100 years and ranges from simple recollections to replicated laboratory studies. The full range of plant responses to all but the most intense fires can be found. Differing responses to fire are caused by a host of factors, many of which are mentioned in Wade and Johansen (1986). We speculate that three of the most important factors affecting survival and subsequent growth are the timing of defoliation, level of defoliation, and species differences in bud development. These factors are discussed in this paper. In addition, an ongoing field study designed to assess the importance of defoliation upon southern pine survival and growth is outlined. Growth differences 3 months after defoliation and visual impressions 6 months after defoliation are described.

## BACKGROUND

Plant tissue is killed when its lethal time-temperature combination is reached. A commonly accepted temperature for near-instantaneous death is 140°F (Byram 1948). Temperatures of 115°F will also kill plant cells if they are sustained for several hours according to work reviewed by Hare (1961) and McArthur (1980), but prescribed burns are not likely to elevate temperatures for that long a period. Yellow to bronze foliage immediately after a fire is a sure indicator that a lethal heat dose was applied; the discolored needles are in fact dead. Charred or partially consumed needles indicate that the ignition temperature of cellulose (about 450° F) was reached. These mortality and ignition thresholds are increasingly likely to be met as the ambient air temperature increases. Summer fires often occur when ambient temperatures are 30 to 60°F higher than those associated with winter fires. Moreover, temperatures of the upper tree crowns can be higher than the surrounding air due to solar heating. Thus, little additional heat is required to raise needles to their lethal temperature threshold during summer burns.

Even with cool winter temperatures, southern pines can suffer complete crown scorch, but they also routinely survive provided they are larger than about 2 inches d.b.h. and no foliage is actually consumed. Crown damage from fires during the growing season is generally more severe, and its consequences are more serious. We believe this differential survival between seasons is primarily a function of bud-kill. When bud-kill is combined with defoliation, a much more life-threatening situation exists. Crown scorch does not automatically signify bud-kill in the four major southern pine species because the buds of these species, especially longleaf (*Pinus palustris* Mill.), are thicker than the needles. Because the rate of temperature rise is inversely proportional to thickness, either higher temperatures or lower sustained temperatures are necessary to kill the buds of such species. There are no obvious signs to enable an observer on the ground to differentiate between completely scorched trees with and without bud damage if needles have not been consumed.

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[1]Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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For species with needles at least equal to their buds in thickness, crown scorch is a reliable indicator of crown kill. These species also tend to have fine branches which are easily heat-killed, even though the branch tips may temporarily survive because the needle clusters form a protective sheath around them. Regardless of the protective mechanism, a given tree is much more likely to suffer crown damage during a summer fire because of higher ambient temperatures.

## BUD DEVELOPMENT AND TIMING OF DEFOLIATION

Most northern temperate zone pines have preformed buds. That is, their winter buds contain all the unexpanded shoots for the following season's growth. These species are thus confined to a single growth flush each year. After dormancy is broken in the spring, the shoots elongate fairly rapidly (1 to 2 months) and then form next year's buds.

The four major southern pine species, on the other hand, undergo multiple flushes because their winter buds do not contain all the shoot primordia for the following growing season. When dormancy is broken in the spring, the terminal bud expands into a shoot and a second bud forms at the apex of the shoot. That bud elongates to extend the initial shoot, and another bud is formed. Southern pines generally undergo three to four flushes during the growing season although as many as seven have been recorded in the literature (Wakeley and Marrero 1958). Depending upon species and environmental conditions, the buds that form after the first flush may open immediately upon formation or after varying periods of time (Romberger 1963). Defoliation, especially early in the growing season, has been shown to stimulate the rapid opening of buds regardless of whether the species has preformed buds or is multinodal. Later in the summer, however, defoliation will not elicit the same response--apparently due to a shortening of the photoperiod, so the defoliated tree remains naked until the following spring.

Complete defoliation of any evergreen has dire consequences with damage a function of the length of time the tree is without foliage. It has been demonstrated that root system recovery after defoliation is directly related to the length of time the trees are defoliated. Kozlowski (1971) presents a synopsis of the evidence that shows root growth is governed by the supply of photosynthetic products and growth-regulating hormones from the crown. The reduction in live root mass following severe insect defoliation is well documented (Swain and Craighead 1924, Redmond 1959, Gregory and Wargo 1986). However, published data relating fire defoliation to growth responses and mortality are, at first glance, without pattern and in some instances appear to be contradictory. Separation of this literature by season of defoliation and bud development markedly clarifies the picture. In species with preset buds, complete defoliation any time during the growing season will result in death (e.g. Craighead 1940, O'Neil 1962, Methven 1971), while in the multinodal southern pines, the damage is most severe following defoliation late in the growing season (Allen 1960, Beal 1942, Bruce 1956, Wade and Ward 1975).

## FIELD STUDY

In an attempt to determine the importance of season and level of defoliation and to assess the magnitude and duration of any growth responses in southern pine, we installed a defoliation study in 4-year-old loblolly pine (P. taeda L.) and slash pine (P. elliottii Engelm.) plantations. A factorial experiment (4x5) with a random mixed block design was established at 4 locations (2 per species). Fifteen blocks were used at each location. One of five levels of defoliation (0, 33, 66, 95, or 100 percent) and one of four seasons of defoliation (January, April, July, or October) were assigned to each of 20 trees within a block. Needles were hand removed during the first 2 weeks of each treatment month.

Pretreatment d.b.h. and height were measured on all 1200 trees during the 1985-86 dormant season. The April, July, and October defoliation took place as scheduled. While applying the October treatments, we formed several visual impressions regarding the trees defoliated earlier in the growing season. Those trees defoliated 6 months previously (April) had all refoliated, undergone several flushes, and looked healthy. The trees defoliated in July, on the other hand, had all refoliated but had not undergone as many post-defoliation flushes and, thus, had sparser crowns. In many instances the needles on the July trees also appeared to be somewhat chlorotic.

Heights and d.b.h.'s of the trees defoliated in April were remeasured in July. Growth differences between defoliation levels are striking (Table 1). Three-month diameter growth was commensurate with the level of defoliation. Diameter growth of the completely defoliated trees was 34 and 36 percent of the non-defoliated trees for loblolly and slash pine, respectively. The same general trend was found in height growth, though species differences were greater--62 percent in slash pine and 45 percent in loblolly pine. In three of the four locations, trees that had the lower 33 percent of their crowns removed outgrew the controls in height during the first half of the growing season. All trees are scheduled for remeasurement during the 1986-87 and 1987-88 dormant seasons.

Table 1.--Three-month growth responses of southern pine subjected to five levels of defoliation during early April 1986.

| Location | DBH Percent Defoliation | | | | | Height Percent Defoliation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 33 | 66 | 95 | 100 | 0 | 33 | 66 | 95 | 100 |
| Slash pine GA For. Comm. Waycross, GA | 100 | 100 | 73 | 43 | 46 | 100 | 99 | 85 | 79 | 63 |
| Slash pine Union Camp Corp. Palatka, FL | 100 | 82 | 44 | 35 | 26 | 100 | 100 | 99 | 67 | 61 |
| Loblolly pine Int. Paper Co. Bainbridge, GA | 100 | 79 | 70 | 47 | 34 | 100 | 100 | 94 | 67 | 53 |
| Loblolly pine Westvaco Corp. Branchville, SC | 100 | 82 | 65 | 40 | 32 | 100 | 102 | 77 | 59 | 38 |

[1]Expressed as a percentage of the growth of trees with no defoliation.

## SUMMARY

All study trees, including those completely defoliated at the beginning of the growing season or halfway through the season, had refoliated and were alive as of early October. However, both diameter and height growth had been severely retarded, especially with the more severe levels of defoliation. At this time we can only speculate on future growth losses or mortality, although some of the July defoliated trees show signs of trauma in the form of yellowing in the new-growth needles. When the full impact of these crown damage treatments has been assessed, the results will have obvious implications in the scheduling of prescribed fire as well as in interpreting literature reports on "fire treatment" used to measure fire effects.

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## Hardwood Regeneration

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# REGENERATION OF APPALACHIAN UPLAND HARDWOOD STANDS SEVEN YEARS AFTER CLEARCUTTING[1/]

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Abstract. Stand composition and structure are evaluated in nine Appalachian oak stands along a topographic moisture gradient seven years after clear felling. Site index ranged from 37 to 71 (base age 50 for upland oaks). Seven years after harvest, the number of well-established oak stems of advanced regeneration origin was larger in stands of site index 55-65 and smaller in sites of higher and lower quality. An accelerated rate of canopy closure occurred with increasing site quality, and stump sprouts were substantially taller than seedling sprouts or advanced regeneration. The abundance of various types of oak regeneration varied with site quality. Canopy closure has occurred on the medium- and higher-quality sites. Low-quality sites are poorly stocked, and oak sprouts remain multiple-stemmed in appearance because of little competition from the sides. Pines have begun to seed in the open areas, but due to their low numbers it appears that oaks will dominate the sites. Quantitative results characterizing stand composition and structure are presented.

## INTRODUCTION

The deeply dissected terrain of the Ridge and Valley Physiographic Province of Virginia exhibits large variations in site quality. Associated with these changes in site quality are noticeable changes in overstory and understory composition in 60-to 80-year-old second growth forests (McEvoy et al. 1980). Variation in composition and growth across sites should also be evident following disturbance, reflecting the differences in site characteristics (amount of litter, radiation, etc.) and/or site potential.

The Ridge and Valley is characterized by a series of northeast to southwest tending ridges separated by wide valleys. The midslope positions on southeastern exposures are dominated by various mixtures of chestnut oak (*Quercus prinus* L.), scarlet oak (*Q. coccinea* Muenchh.), and black oak (*Q. velutina* Lam.) (Braun 1950; Whittaker 1956; Day and Monk 1977; McEvoy et al. 1980). The proportions of these species vary with changes in site quality (Braun 1950; Whittaker 1956; McEvoy et al. 1980). On the drier south-to-southwest facing ridges and slopes, pitch pine (*Pinus rigida* Mill.) and Table Mountain pine (*P. pungens* Lamb.) increase in number while black oak decreases.

There is a significant acreage dominated by poor quality upland hardwoods, and there appears to be potential to improve both the quality and quantity of stems following clearcutting. Several studies have quantified the effects of harvesting on upland hardwood sites (Lamson 1976, Mann 1984, McGee 1980). The objective of this study was to quantify canopy development and species composition across site qualities in Appalachian upland hardwood stands 7 years after clearcutting. The present study is part of a long term project initiated in 1977 by Virginia Polytechnic Institute and State University in cooperation with the U.S. Forest Service to study the effects of whole-tree harvesting on upland hardwood stands.

## STUDY AREA

The study is located at a midslope position on the southeast slope of Potts Mountain in Craig County, Virginia. The approximate elevation is 2500 feet, and slopes average 30 to 40 percent. Parent materials are nutrient poor sandstones and shales and usually give rise to coarse-textured, shallow, and strongly leached soils (Morin 1978). Annual precipitation is 38 inches and is evenly distributed throughout the year. The frost-free growing season is approximately 160 days. The range in site quality is from $SI_{50}$ 37 to $SI_{50}$ 71 for upland oaks. All site index references refer to that of upland oaks at base

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age 50 as determined from the curves of Olson (1959).

The study sites were characterized by the study sites were characterized by the overstory species mix as well as the quantity and composition of the understory. Four distinct vegetation types were delineated -- mixed pine, mixed oak-pine, mixed oak, and mixed hardwood (McEvoy et al. 1980). Ross (1982a) applied 3 separate productivity indicies to the vegetation types and found a gradient of increasing growth potential in the order mixed pine, mixed oak-pine, mixed oak, and mixed hardwood. Meiners (1981) found the productivity gradient to be closely related to soil moisture during the growing season.

The mixed pine site, $SI_{50}$ 37, is characterized by an overstory dominated by pine with a few oaks scattered throughout (McEvoy et al. 1980). A dense shrub layer dominated by ericads and bear oak (Q. ilicifolia Wang.) is also present. The mixed oak-pine site, $SI_{50}$ 49 upland oak, has an overstory predominated by oak with a few scattered pines. The well-developed understory is dominated by mountain laurel (Kalmia latifolia L.), huckleberry (Gaylussacia baccata (Wang) K. Koch), and blueberries (Vaccinium spp.). The mixed oak site, $SI_{50}$ 59, has a canopy comprised primarily of oaks, and a discontinuous ericaceous understory. The mixed hardwood site, $SI_{50}$ 71, is dominated by more mesic species such as red maple (Acer rubrum L.) yellow-poplar (Liriodendron tulipifera L.), and black locust (Robinia pseudoacacia L.). The shrub stratum is poorly developed, but the herb layer is well-represented.

## METHODS

Nine 0.40 acre plots were established in the fall of 1977 and the spring of 1978. The plots were located along a 3.3 mile midslope road in 3 noncontiguous cutting units totalling 150.7 acres. The number of plots for each vegetation type varies: mixed pine, 3 plots; mixed oak-pine, 1 plot; mixed oak, 3 plots; mixed hardwood, 1 plot; and one control (uncut) plot. Prior to harvest a complete vegetation inventory was made. Three strata were established based on vertical plant height: herb stratum -all stems less than 3.3 feet in height, shrub stratum - woody stems between 3.3 and 16.4 feet in height, and the tree stratum -woody stems greater than 16.4 feet in height.

Between August 1978 and March 1979, all stems >4.9 feet in height were cut back to within 5.9 inches of ground level and removed from the plot. All suitable material was removed from the sites as part of a commercial whole-tree harvesting operation. One mixed oak plot was harvested during August, whereas all others were harvested during the dormant season. Stump sprouts occurred in September and October on the plot harvested during the growing season, but all sprouts were killed by frost before winter.

Since harvest, changes in the vegetation vegetation composition and structure have been documented by repeated inventories. Tree stratum measurements were carried out in March and April of each year (through 1986) and all stems greater than 16.4 feet in height were recorded by species, total height, and dbh. A metal identification tag was attached to each tree in this stratum at approximately 5.9 inches above the forest floor.

Due to the lack of management potential in the two lower quality sites (SI 38 and SI 49), the information for these plots was lumped together and reported as sites with SI <50.

In the spring of 1986, shrub stratum measurements for the seventh growing season were taken. The shrub stratum inventory was a 25 percent sample consisting of 16 randomly chosen subplots (each subplot contains 269 $ft^2$) within each of four plots. These plots represented all four vegetation types delineated by McEvoy et al. (1980). All stems between 3.3 feet and 16.4 feet in height were recorded by species, total height, and diameter at 5.9 inches.

## PREHARVEST STAND SUMMARY

In the preharvest stands, as site index increased, there was an increase in tree basal area from 90 $ft^2$/acre on SI <50 to 120 $ft^2$/acre at SI 70 (Table 1) (McEvoy et al., 1980). The greatest density was also found on the highest quality site. In the shrub stratum, an increase in site quality resulted in a decrease in basal area and shrub density. Shrub basal area was 19.8, 5.2, and 4.8 $ft^2$/acre for SI <50, SI 60, and SI 70, respectively. Average shrub height was substantially higher on SI 70. These trends in basal area and shrub density agree with the reports of Whittaker and Woodwell (1969) for oak-pine forests at Brookhaven, New York.

## RESULTS AND DISCUSSION

Ross et al. (1986) described the oak regeneration on the Potts Mountain study sites 2 years after harvest. They concluded that chestnut oak sprouted more frequently and grew more rapidly than both scarlet and black oak. In general, both stump sprouts and advanced regeneration increased in height with increasing site quality. The density of oak advanced regeneration was greatest on SI 55-65 and decreased on sites of higher and lower quality.

Table 1. Preharvest stand summaries for the tree stratum (all stems >16.4 ft. in height) and the shrub stratum (all stems between 3.3 and 16.4 ft. in height) by site index (upland oaks, base age 50 (Olson 1959)), western Virginia (McEvoy 1978).

| | SITE INDEX | | |
|---|---|---|---|
| STRATUM | <50 | 60 | 70 |
| TREE | | | |
| basal area[1] ($ft^2$/ac) | 90 | 107 | 120 |
| density (#/ac) | 414 | 387 | 478 |
| SHRUB | | | |
| basal area[2] ($ft^2$/ac) | 19.8 | 5.2 | 4.8 |
| density (#/ac) | 3833 | 1479 | 935 |
| average ht. (ft) | 5.6 | 5.3 | 8.2 |

[1] Basal area measured at dbh
[2] Basal area measured 5.9 inches above the forest floor

## Tree Stratum Summary

Recruitment into the tree stratum did not begin until the fourth growing season (Table 2). During the fourth and fifth year black locust was clearly the most common species in the tree stratum. In year 6, chestnut oak and black locust were equally represented, followed in decreasing order by red maple and Amercian chestnut (Castanea dentata (Marsh.) Borkh.). During the seventh growing season, chestnut oak became the dominant species followed by black locust, red maple, American chestnut, and scarlet oak, in decreasing order of abundance. The basal area at year 7, averaged across all sites, was 4.50 $ft^2$/acre.

The hardwood forests of the Ridge and Valley originally contained a large component of American chestnut (Braun, 1950). Loss of the chestnut due to the chestnut blight (Endothia parasitica) had a major impact on the growth of other stems, and, to a lesser extent, on the composition of these stands (Nelson 1955). Chestnut continues to resprout from the original stumps and stems. Our data and observations indicate that the early growth and form of American chestnut is better than all other species, especially on the drier end of the spectrum. If an effective and economical method of inoculating chestnut stems to prevent or cure the blight is developed in the near future, chestnut in recently cutover stands might once again become a major component of these forests.

The tree stratum density is increasing on all sites (Figure 1); however, recruitment is occurring at the fastest rate on SI 70, with a lower rate on SI 60 and SI <50 sites, respectively. The poorest site qualities are developing slowly with only 48 stems/acre at year 7 compared to 980 stems/acre on the highest quality site.

The species composition of the tree stratum also varies across site qualities (Figure 2). With an increase in site quality there is an increase in species diversity in the tree stratum. Areas with SI <50 are dominated almost entirely by oaks at year 7. Site index 60 sites are dominated by oaks and black locust, and SI 70 sites are dominated by red maple, black locust, sassafras (Sassafras albidum (Nutt.) Nees) , yellow-poplar, and oaks, in order of decreasing density. Tree stratum basal area also increases with an increase in site quality (Table 3). At age 7 the basal area ranges from 0.97 $ft^2$/acre on the poorest site to 15.70 $ft^2$/acre on the best site.

On all sites, chestnut oak was the tallest and most abundant oak in the tree stratum, followed by scarlet and black oak. On areas with SI <50 the average diameter of scarlet oak was greater than chestnut oak or black oak: 2.1, 1.9, and 1.7 inches, respectively. However, on the intermediate sites the average diameter for scarlet oak and black oak were equal and they exceeded chestnut oak by 0.3 inches (2.0 vs. 1.7 inches). On the mesic site (SI 70) chestnut oak was the only oak present in the tree stratum. All oaks presently occupying the tree stratum originated from stump sprouts.

## Shrub Stratum at Year 7

A knowledge of the shrub stratum composition is needed in order to properly evaluate the tree stratum composition and how it will develop in the future. The density and basal area of the shrub stratum varies by site quality (Table 4). The major differences are the much larger values for the mixed oak site (SI 60), as compared to the other two; ie. 20,204, 6781, and 6464 stems/acre on sites SI's 60, <50, and 70 respectively. The sites of SI <50 and 70 have approximately equal densities (35.9 vs. 29.8 $ft^2$/acre), with the SI 70 site having more basal area (65.6 $ft^2$/acre). In contrast with these trends, stratum height increased from the xeric to mesic sites.

Table 2. Density and basal area summaries by species for the tree stratum (all stems >16.4 ft. in height) for the entire Potts Mountain study area. Average heights are given for seven-year-old trees. The area was whole-tree harvested during the fall and winter of 1978-79.

| | AGE | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 YEARS | | 4 YEARS | | 5 YEARS | | 6 YEARS | | 7 YEARS | | |
| SPECIES | STEMS (#/ac) | BA ($ft^2$/ac) | STEMS (#/ac) | BA ($ft^2$/ac) | STEMS (#/ac) | BA ($ft^2$/ac) | STEMS (#/ac) | BA ($ft^2$/ac) | STEMS (#/ac) | BA ($ft^2$/ac) | AVG HT (ft) |
| Chestnut oak | — | — | 1 | <0.10 | 8 | 0.15 | 35 | 0.63 | 85 | 1.66 | 18.7 |
| Black locust | — | — | 4 | 0.10 | 18 | 0.32 | 36 | 0.64 | 49 | 1.04 | 20.3 |
| Red maple | — | — | <1 | — | 9 | 0.10 | 26 | 0.32 | 47 | 0.69 | 20.0 |
| American chestnut | — | — | 1 | <0.10 | 9 | 0.15 | 13 | 0.22 | 18 | 0.31 | 18.2 |
| Scarlet oak | — | — | — | — | — | — | 1 | <0.10 | 11 | 0.24 | 17.7 |
| Other/1 | — | — | — | — | 2 | <0.10 | 7 | 0.10 | 40 | 0.56 | 17.9 |
| Total | — | — | 6 | 0.10 | 46 | 0.75 | 118 | 1.93 | 250 | 4.50 | 19.1 |

[1] Other includes black oak, sourwood, blackgum, yellow-poplar, sassafras, witch-hazel, mockernut.

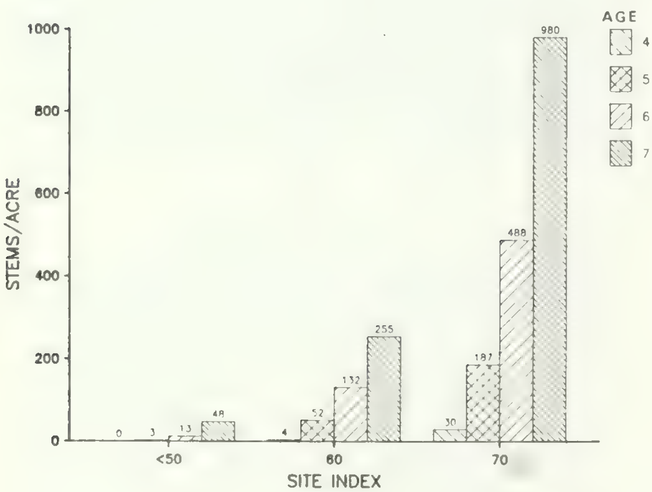


Figure 1. Tree stratum density (all stems >16.4 ft. in height) by age and site index (base age 50, upland oaks (Olson (1959)), upland hardwoods, western Virginia.

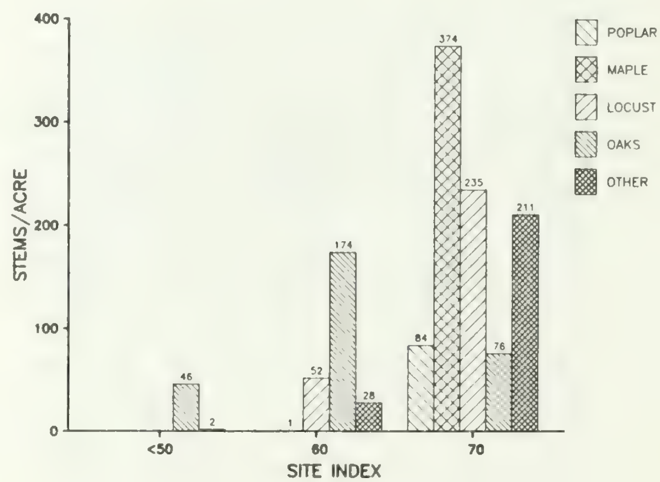


Figure 2. Seven year upland hardwood tree stratum densities (all stems >16.4 ft. in height) by species and site index (base age 50, upland oaks (Olson 1959)), seven-year upland hardwood stands, western Virginia.

Table 3. Density and basal area summaries for the tree stratum (all stems >16.4 ft.) of seven year old upland hardwood stands by site index (base age 50, upland oaks (Olson 1959)), western Virginia.

| SITE INDEX | SPECIES | STEMS (#/ac) | BASAL AREA[1] ($ft^2$/ac) |
|---|---|---|---|
| <50 | Oaks | 46 | 0.93 |
| | American chestnut | 1 | 0.02 |
| | Sourwood | 1 | 0.02 |
| | Totals | 48 | 0.97 |
| 60 | Oaks | 174 | 2.67 |
| | Black locust | 52 | 1.15 |
| | American chestnut | 19 | 0.30 |
| | Red maple | 1 | 0.01 |
| | Other | 9 | 0.23 |
| | Totals | 255 | 4.36 |
| 70 | Red maple | 374 | 5.56 |
| | Black locust | 235 | 4.98 |
| | Chestnut oak | 76 | 1.36 |
| | Sassafras | 121 | 1.34 |
| | Tulip poplar | 84 | 1.12 |
| | Other | 90 | 1.34 |
| | Totals | 980 | 15.70 |

[1] Basal area measured at dbh.

Table 4. Summaries of density, average height, and basal area for the shrub stratum (all stems between 3.3 and 16.4 feet in height) under seven year old upland hardwood stands by site index (base age 50, upland oaks (Olson (1959)), western Virginia.

| SITE INDEX | STEMS (#/ac) | AVG. HT. (ft) | BA[1] ($ft^2$/ac) |
|---|---|---|---|
| <50 | 6781 | 5.1 | 29.75 |
| 60 | 20204 | 7.3 | 65.57 |
| 70 | 6464 | 9.4 | 35.92 |

[1]Basal area measured at 5.9 inches above forest floor

Many of the plants presently growing in the shrub stratum will eventually move into the tree stratum. Figure 3 shows the number of stems by species for each site quality that are present in the tree stratum at 7 years, plus those which have the potential to move into the tree stratum. Selection of possible recruits was on the basis of growth form. A brief discussion of the composition and probable development of each site follows.

### Site Index <50

The shrub stratum on low quality sites is is dominated by sassafras, blackgum (*Nyssa sylvatica* Marsh.), oaks, and red maple. Scarlet oak is more abundant than chestnut oak. Our data show that the majority of the oak stems present in the shrub stratum are stump sprouts. Due to the poor site quality it is unlikely that many red maple, blackgum, or sassafras will become part of the dominant canopy. Because only 40 pine stems/acre are present, it appears that these lower quality sites will be dominated by oaks in the future.

### Site index 60

The shrub stratum is presently dominated by sassafras, oaks, blackgum, maple, and hickory, in order of decreasing abundance. The large recruitment of sassafras following disturbance is typical of many pioneer species. These species colonize in high numbers immediately after disturbance, but die out quickly (Marks and Bormann 1972, Ross et al. 1982b). Therefore, sassafras is not expected to be a significant component of the canopy. However, it may play a vital role in the maintenance of site quality. Preharvest data indicated sassafras tissues were consistently above-average in nitrogen, phosphorus, and potassium concentrations (Martin et al. 1982). Pioneer species can be important in reducing nutrient losses from the site by functioning as a nutrient sink following canopy removal or similar disturbance (Marks and Bormann 1972; Boring et al. 1981).

The tree stratum on these sites is currently dominated by oaks and black locust. The large number of oaks present in the shrub stratum - mainly advance regeneration - indicates that the site will continue to be dominated by oaks. However, black locust will also be a major component. Although there are only 61 black locust stems/acre in the shrub stratum, most of these are near the upper limit of the stratum height and thus have a high probability of making it into the canopy.

### Site Index 70

Both the preharvest and the 7-year postharvest tree strata contained a greater diversity than that which was found on lower site qualities. The tree stratum is currently dominated by red maple, black locust, sassafras, yellow-poplar, and oaks, in decreasing order of abundance; whereas the shrub stratum is dominated by sassafras, red maple, blackgum, yellow-poplar, black locust, and oaks. Although the sassafras and blackgum are growing faster on this site than on the others, it is doubtful that they will maintain their dominance. First, they are below the level of the dominant red maple, black locust,

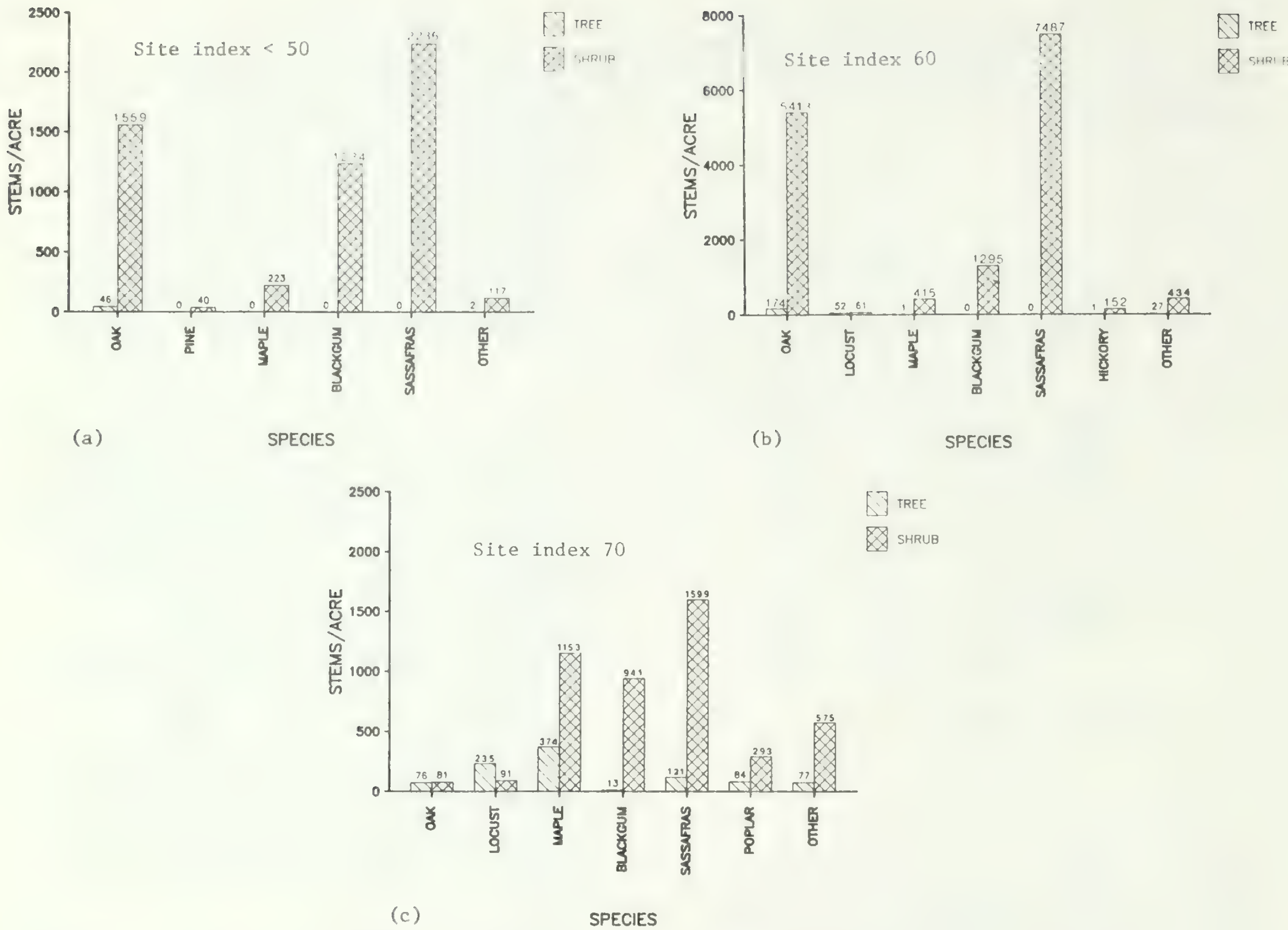


Figure 3. Number of stems by species that are present in the tree stratum (all stems >16.4 ft. in height) plus those stems which have the potential to move from the shrub stratum (all stems between 3.3 and 16.4 ft. in height) into the tree stratum. Selection of possible recruits was on the basis of growth form. Data are summaries after seven growing seasons in upland oak stands with site index <50 (a), site index 60 (b), site index 70 (c), (base age 50, (Olson 1959)) in western Virginia.

and yellow-poplar. And secondly, sassafras is a short-lived species as evidenced by its lack of presence in the preharvest canopy. Therefore, the mature forest canopy will probably be a mixture of red maple, black locust, yellow-poplar, and oak with sassafras and blackgum scattered throughout.

## CONCLUSIONS

The Ridge and Valley Physiographic Province of southwestern Virginia is a deeply dissected region that contains a wide range of site qualities. Because substantial site quality variations can occur in a few hundred feet, it is important for the forest manager to realize the effects this variation in site quality has on the composition and growth of hardwood stands following harvest.

In upland hardwood stands of site index <50 recruitment of the oaks into the tree stratum has been slow during the first 7 years. Recruitment from the shrub stratum will continue to occur but at a very slow rate. When the number of potential crop trees is calculated (taking into account sprout clumps) and the lack of competition from the side (to produce reasonably straight stems) are

considered (Ross et al. 1986), it is apparent that production of usable wood will be quite low. Thus it appears that sites with SI <50 for upland oaks could be a cutoff for active forest management for timber production.

Upland hardwood stands with site indices between 50 and 70 are heavily stocked with oak regeneration and the future stand will probably be dominated by oaks.

The most mesic stand on these slopes, SI $\geq$ 70, is currently dominated by red maple and black locust; the oaks are a relatively minor component. Compared to the other sites, the tree stratum is more diverse. Some species will decline very soon (e.g. sassafras) or within the next 30-40 years, (e.g. black locust). However, a number of other species (yellow-poplar, sourwood, hickory, sweet birch) have sufficient longevity to be present for 50-100 years or longer. Therefore, the oak component will probably remain a distant third to red maple and yellow-poplar with the miscellaneous species approximately equal to the oaks in importance.

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# REGROWTH AFTER COMPLETE HARVEST OF A YOUNG BOTTOMLAND HARDWOOD STAND[1/]

John K. Francis[2/]

Abstract.--An 11-year-old bottomland hardwood stand growing on poorly drained clay soil on the Mississippi River floodplain was harvested to determine yield and composition of the regrowth. Green ash made up 82% of the stems in the parent stand but comprised only 29% of the stems in the new stand 4 years after coppicing. Green ash was present in all plots, however, and produced the tallest stem in 81% of the plots. Cedar and American elm accounted for most of the remaining tree stems. Although bottomland oaks comprised a small proportion of the stems in the 11-year-old stand, they were widely distributed and coppiced vigorously. Dry woody biomass in year 4 reached 15 t/ha for an average annual yield of 3.7 t/ha. In year 1, yield of herbaceous plants (3.5 t/ha) was nearly as great as yield of woody species (5 t/ha), but declined to almost nothing in year 4. Due to the simultaneous decrease of herbs and the increase of woody species, total nutrient content in summer biomass changed little from year to year over the 4 years of monitoring. It appears that if the coppice stand is allowed to mature, it will contain significant proportions of ash, elms, and oaks.

## INTRODUCTION

Future industrial processes may routinely accept heterogeneous biomass for the production of fiber, chemical, or biological products. Because young stands are more adaptable to mobile continuous flow harvesting equipment, they may eventually be a preferred source of biomass. The use of young stands was envisioned a number of years ago (McAlpine and others 1966), extensively studied, and used to a limited extent (Mattson and Winsauer 1985). While plantations may be grown specifically for biomass, in the real world of forest industry expensive plantations will not be extensively established while abundant natural stands remain unexploited.

Before complete harvest of young bottomland hardwood stands begins, foresters should have a good idea of what will grow to replace these stands and how the regrowth will develop. Also of concern is whether future productivity will be impaired by harvest of young stands.

In an earlier publication (Francis 1984), I described the yield and nutrient content of the young stand that was harvested to produce the regrowth discussed in this paper. Others have studied yields from harvests of sapling stands (Hitchcock 1979, Krinard and Johnson 1981). However, the effects of the harvest of sapling stands on the composition of regrowth are generally unknown. Regrowth of young upland southern hardwood stands after fire was documented by McGee (1980). In that study, the number of dominant red maple (Acer rubrum) increased while the competitive position of the oaks (Quercus spp.), yellow-poplar (Liriodendron tulipifera), black cherry (Prunus serotina), and white ash (Fraxinus americana) remained about the same.

## Methods

The stand selected for this study was located near Stoneville, MS. The original stand had been a tract of mature bottomland hardwoods prior to clearcutting in 1969. The main tree species present at clearcutting were: Nuttall oak (Quercus nuttallii), willow oak (Q. phellos), overcup oak (Q. lyrata), sweetgum (Liquidambar styraciflua), American elm (Ulmus americana), sugarberry (Celtis laevigata), and green ash (Fraxinus pennsylvanica).

Most of the regeneration was from seeds or former understory seedlings. At the time this study was begun, the regenerated stand was 11 years old and, predominantly green ash (82 percent of the stems and 59 percent of the dry weight). Other important tree species were: American elm, black willow (Salix nigra), eastern cottonwood (Populus deltoides), and red maple. Oaks, sweetgum, and sugarberry were rarely encountered. Dry-weight yields were 41.6 t/ha for summer and 35.8 t/ha for winter (Francis 1984). The soil in this flat and poorly drained area was in the Alligator series --- very fine, montmorillonitic, acid, thermic Vertic Haplaquepts. Four 0.13 ha blocks were cut in the winter of 1981-82. The blocks were located on the site by dividing the area available for sampling (about 4 ha) into four equal sections and randomly positioning a block within each section. All vegetation in the blocks was

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severed near the groundline and removed from the area. Four 0.004-ha plots per block, with buffer zones around each, were laid out for future sampling. The assignment of treatments within each block was random. Each plot was split into two 0.002-ha subplots for summer and winter sampling. In each of the 4 years of the study, one plot from each block was sampled. Summer sampling took place during August and winter sampling in December or January. In years 1 and 2, all vegetation within the subplot was cut, and herbaceous and woody vegetation were weighed separately. Herbaceous vegetation was not sampled during the winter. Then the entire harvest was ovendried and weighed again. A subsample for nutrient analysis was extracted from each sample. In years 3 and 4, individual stems of tree and brushy species were measured for height and weight. A sample of each species was dried to enable a projection of total dry weight from green weight. The separate weighing of trees, shrubs, and vines enabled reporting of mass for those stand components in years 3 and 4.

The semimicro kjeldahl procedure was used to obtain values for nitrogen, and the molybdenum blue method was used for phosphorous. Potassium, calcium, and magnesium were measured by atomic absorption spectrophotometry after being taken up in dilute acid from ashed tissue. Mean and standard deviation were used to analyze the data.

## Results and Discussion

New growth began to appear in March after removal of the sampling stand. By the August sampling, sprouts and herbaceous weeds were chest-high, thick, and often matted. The most abundant herbaceous weed the first year was Pennsylvania smartweed (Ploygonum pennsylvanicum). Cottonwood, which produced weak and spindly sprouts, was dragged down and smothered in the dense mat of weeds. Many green ash and American elm grew ahead of the early flush of weeds; most others apparently survived the first-year matting. The weeds were much thinner in the slight rises of ground, which were probably drier. During the second year, smartweed decreased markedly while goldenrod (Solidago sp.) increased. In the third year, goldenrod was the dominant herbaceous species. By the fourth year, shade from the trees had increased enough to eliminate most herbaceous growth. The herbaceous growth that did occur was mostly confined to gaps between the tree sprout clumps. Weights per hectare of herbaceous species in the August sampling approximate the annual yield (table 1). The greatest yield occurred during the first year. Somewhat lower in years 2 and 3, herbaceous yields decreased to almost nothing in year 4.

Standing woody biomass increased steadily through the 4 years. The difference between summer and winter weights (approximately the weight of leaves) increased over the years but showed no clear trend in terms of percentage of total biomass. The largest annual increase in standing woody biomass occurred in year 1 and decreased each year through year 4. The 4-year average annual increase of woody biomass (calculated from dry woody biomass, summer of year 4) was 3.68 t/ha. This yield is comparable to the 3.25 t/ha/yr obtained from the original stand (Francis 1984), 2.47 t/ha/yr measured by Hitchcock (1979) from upland oak-hickory regeneration 4 years after a clearcut harvest, and 1.84 to 3.48 t/ha/yr for speckled alder (Alnus rugosa) in the Lake States (Mattson and Winsauer 1985). Krinard and Johnson (1981) harvested the equivalent of 3.63 t/ha/yr from an 11-year-old seeded oak stand containing a mixture of volunteer species, and 4 years later recorded 7.85 t/ha/yr of biomass from the coppice regrowth (Krinard and Johnson 1986). This higher yield was most likely a result of higher individual-tree vigor gained through lower density and less competition.

Table 1.-- Biomass harvested from sample plots in each of 4 years

| Type of sample | Year 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| | Metric tons/hectare | | | |
| Summer green herbaceous | 11.5 $\pm$ 4.4* | 5.2 $\pm$ 2.3 | 5.5 $\pm$ 2.9 | 1.0 $\pm$ 0.8 |
| Summer dry herbaceous | 3.5 $\pm$ 1.0 | 1.8 $\pm$ 0.8 | 2.2 $\pm$ 1.3 | 0.3 $\pm$ 0.2 |
| Summer green woody | 12.5 $\pm$ 3.9 | 20.1 $\pm$ 6.1 | 22.0 $\pm$ 9.3 | 28.2 $\pm$ 5.2 |
| Summer dry woody | 5.0 $\pm$ 1.6 | 9.3 $\pm$ 2.8 | 12.2 $\pm$ 5.4 | 14.7 $\pm$ 2.8 |
| Winter green woody | 5.9 $\pm$ 4.3 | 13.2 $\pm$ 4.1 | 17.5 $\pm$ 3.6 | 18.3 $\pm$ 9.0 |
| Winter dry woody | 3.5 $\pm$ 2.5 | 8.1 $\pm$ 2.8 | 8.0 $\pm$ 1.9 | 10.8 $\pm$ 5.4 |

* mean $\pm$ standard deviation; n = 4 in each case

The number of stems per hectare in years 3 and 4 averaged 30,063 and 29,077 respectively and included both trees and shrubs. The proportion of species in the regrowth changed considerably from the former stand. Green ash in years 3 and 4 averaged only 29 percent of the stems; however, it was present on all plots sampled. Generally, just the largest and most vigorous ash stems from the previous sampling stand coppiced. Those coppicing, however, produced an average of 3.9 sprouts per stump. The second most abundant tree in terms of total number of stems in the regrowth was cedar elm (Ulmus cressifolia). Although unimportant in the previous stand, it sprouted vigorously and produced a large number of stems per sprout clump. American elm was also an important tree component of the regrowth. It produced sprouts that were slightly taller and more robust than those of cedar elm. Other species represented in the regrowth were water hickory (Carya aquatica), sugarberry, water oak, willow oak, and Nuttall oak. Black willow and cottonwood had disappeared completely. Sugarberry was very short and weak compared to the other species. The oaks, unimportant in terms of percentage of total stems in the original stand, increased their prominence by nearly universal survival and production of a large number of stems per stool. At least one oak was present on 38 percent of the 0.002 ha plots sampled in years 3 and 4. Green ash produced the tallest individual on 81 percent of the plots. The average tallest trees per plot in years 3 and 4 were 4.3 m and 4.8 m respectively. The reproduction of trees in sprout clumps could result in more multiple-stemed trees whose average size would be smaller with poorer form than if these trees reproduced from seed or seedling sprouts.

Brushy species accounted for 21 percent of the stems measured in years 3 and 4. There were mainly possumhaw (Ilex decidua) and hawthorn (Crataegus opaca), with a few roughleaf dogwood (Cornus drummondii) and elderberry (Sambucus canadensis). These will undoubtedly be overtopped soon. Woody vines that contributed 29.2 and 15.0 percent of the summer woody biomass in years 3 and 4 were: blackberry, Rubus sp.; trumpetcreeper, Campsis radicans; moonseed, Menispermum canadense; supplejack, Berchemia scandens; poison-ivy, Toxicodendron radicans; Carolina jassamine, Gelsemium sempervirens; and wild grape, Vitis aestivalis. The reduction in vine biomass may have been due to two processes: the steady increase in tree and shrub biomass and the death of certain vines. Many trumpetcreepers surviving from the original stand grew for a couple of years and then died. Also, many blackberry canes, which normally live 2 years, did not renew themselves after the initial flush because of increased shade. By year 4, only supplejack had seriously invaded the crowns of some of the trees. A vine stage in which large areas of tree crowns are matted down and held in check for 10 years or more does not appear likely to develop in at least the next 2 or 3 years, if at all.

Nutrient concentrations (N, P, K, Ca, and Mg) in harvested materials in years 1 through 4 are listed in table 2. The accumulation of nutrients

Table 2.-- Average nutrient concentrations in biomass harvested from plots over a 4-year period

| Season | Tissue | Nutrient | Year 1 | Year 2 | Year 3 | Year 4 |
|---|---|---|---|---|---|---|
| | | | Percent | | | |
| Summer | Herbaceous | N | 1.07 ± 0.07* | 1.40 ± 0.29 | 1.08 ± 0.20 | 0.86 ± 0.21 |
| Summer | Woody | N | 0.83 ± 0.10 | 0.67 ± 0.32 | 0.58 ± 0.15 | 0.65 ± 0.10 |
| Winter | Woody | N | 0.57 ± 0.10 | 1.14 ± 0.35 | 0.51 ± 0.07 | 0.62 ± 0.11 |
| Summer | Herbaceous | P | 0.18 ± 0.02 | 0.19 ± 0.02 | 0.14 ± 0.02 | 0.18 ± 0.04 |
| Summer | Woody | P | 0.14 ± 0.02 | 0.12 ± 0.04 | 0.08 ± 0.01 | 0.09 ± 0.01 |
| Winter | Woody | P | 0.08 ± 0.01 | 0.17 ± 0.05 | 0.07 ± 0.01 | 0.08 ± 0.03 |
| Summer | Herbaceous | K | 1.64 ± 0.32 | 1.16 ± 0.56 | 0.99 ± 0.13 | 2.26 ± 0.51 |
| Summer | Woody | K | 0.58 ± 0.12 | 0.86 ± 0.70 | 0.33 ± 0.07 | 0.42 ± 0.01 |
| Winter | Woody | K | 0.28 ± 0.03 | 1.27 ± 0.73 | 0.24 ± 0.03 | 0.25 ± 0.07 |
| Summer | Herbaceous | Ca | 0.84 ± 0.14 | 1.02 ± 0.15 | 0.96 ± 0.25 | 1.00 ± 0.41 |
| Summer | Woody | Ca | 0.67 ± 0.06 | 0.57 ± 0.16 | 0.55 ± 0.17 | 0.75 ± 0.07 |

Table 2.--(cont'd).

| Season | Tissue | Nutrient | Year 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| | | | Percent | | | |
| Winter | Woody | Ca | 0.56 ± 0.09 | 0.82 ± 0.15 | 0.45 ± 0.10 | 0.57 ± 0.05 |
| Summer | Herbaceous | Mg | 0.25 ± 0.06 | 0.26 ± 0.07 | 0.17 ± 0.03 | 0.20 ± 0.10 |
| Summer | Woody | Mg | 0.12 ± 0.02 | 0.13 ± 0.04 | 0.07 ± 0.02 | 0.10 ± 0.05 |
| Winter | Woody | Mg | 0.08 ± 0.02 | 0.20 ± 0.07 | 0.05 ± 0.00 | 0.09 ± 0.03 |

* mean ± standard deviation; n = 4 in each case

(kilograms per hectare) in harvested summer biomass are listed in table 3. Due to the simultaneous decrease of herbs and the increase of woody species, there were relatively minor changes in total nutrient content of the summer biomass over the 4 years of regrowth. Although substantial quantities of nutrients are withdrawn by harvesting regrowth on very short rotations, this particular soil (Alligator) has huge reserves of nutrients (Francis 1984) and could supply nutrients to succeeding stands through several rotations.

The regrowth resulting from the harvest of an 11-year-old bottomland hardwood stand dominated by green ash produced total biomass at a rate similar to the parent stand. A species shift away from ash and toward elm and oak has occurred as a result of cutting. If left undisturbed, the future stand developing from this setting would have sizable components of ash, elm, and oak.

Table 3.-- Nutrient accumulated in biomass harvested over a 4-year period

| Nutrient | Tissue | year 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| | | kilograms per hectare | | | |
| N | Herbaceous | 37.5 | 25.8 | 24.0 | 2.6 |
| | Woody | 41.2 | 62.7 | 75.8 | 96.0 |
| | Total | (78.7) | (88.5) | (99.8) | (98.6) |
| P | Herbaceous | 6.2 | 3.6 | 3.1 | 0.6 |
| | Woody | 6.9 | 10.7 | 9.5 | 13.9 |
| | Total | (13.1) | (14.3) | (12.6) | (14.5) |
| K | Herbaceous | 57.3 | 21.5 | 22.0 | 6.9 |
| | Woody | 33.7 | 80.0 | 40.4 | 62.1 |
| | Total | (91.0) | (101.5) | (62.4) | (69.0) |
| Ca | Herbaceous | 29.4 | 18.9 | 21.5 | 3.1 |
| | Woody | 33.4 | 53.4 | 67.2 | 111.1 |
| | Total | (62.8) | (72.3) | (88.7) | (114.2) |

Table 3.--(cont'd).

| Nutrient | Tissue | year 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| | | kilograms per hectare | | | |
| Mg | Herbaceous | 8.8 | 4.9 | 3.7 | 0.6 |
| | Woody | 6.2 | 11.9 | 8.6 | 14.1 |
| | Total | (15.0) | (16.8) | (12.3) | (14.7) |

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# REGENERATION OF BOTTOMLAND HARDWOOD SITES BY PRE-HARVEST PLANTING [1/]

J. L. Chambers, H. C. Stuhlinger, and R. G. P. Clifton [2/]

Abstract.--Twenty one-hectare circular treatment plots were established in an over-mature cottonwood-willow stand in south-central Louisiana. Seedlings of baldcypress, green ash, sweet pecan, water oak, and Nuttall oak were planted within a 0.25 ha circular nested plot on each treatment plot. All seedlings were then allowed to establish themselves for a period of one year before harvesting treatments were applied. Five harvest level treatments replicated four times were applied in a randomized design. Harvest treatments consisted of removal of 30, 45, 60, 75, or 100 percent of the plot basal area. A conventional harvest of sawtimber trees took place during the second spring and summer after planting. Additional non-commercial trees were then felled to reach specified harvest levels for each respective treatment. Survival and growth were evaluated for harvesting effects at the end of the growing season. First-year survival ranged from 88 to 99 percent and height growth was greatest for green ash and Nuttall oak. At the end of the growing season following harvest (second growing season in the field), survival ranged from 50 to 70 percent. Mortality from harvesting was estimated to range from 17 to 23 percent. Height growth was slow but adequate for the species studied. Green ash and Nuttall oak showed the most rapid height growth with 39 and 30 percent of the seedlings, respectively, exceeding a height of 1 m after 2 growing seasons in the field.

## INTRODUCTION

Regeneration of bottomland hardwoods has been a subject of considerable research. Well established methods exist for regeneration of bottomland hardwood stands which have desirable species composition and adequate advanced regeneration (Johnson 1985). However, many high-graded stands exist which have undesirable overstory composition , midstories of tolerant slow growing species and understories with inadequate or undesirable advanced regeneration (Carvell and Tryon 1961, Janzen and Hodges 1985). In other cases the forest manager may simply want to increase the numbers of certain preferred species in the new stand. The most prevalent means of reproducing stands with these undesirable attributes is to clearcut and plant. However this type of operation is capital intensive, often requiring intensive site preparation, and several years of continued cultural practices. In addition, clearcutting may be an unacceptable regeneration practice on some areas or for some ownership objectives. Underplanting or pre-harvest planting is one method that may have potential for rectifying the inadequate advanced regeneration problem (Tworkoski et al. 1983, Nix et al. 1985). Pre-harvest planting may also provide an alternative to the often used clearcut and plant regeneration method.

The objectives of this paper are to: describe the initial success of underplanted seedlings; evaluate the impacts of animal damage on pre-harvest planted seedlings, and describe the effects of logging activities on survival of the pre-harvest planted seedlings. Future work will evaluate the effects of various levels of overstory removal and understory control on the ultimate success of this regeneration method.

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## METHODS AND PROCEDURES

### Study Area

The study area is located in the Atchafalya river basin in south-central Louisiana. This site, provided by Williams Inc., is a 32.4 ha bottomland hardwood site with an overstory primarily of over-mature cottonwood (Populus deltoides), and black willow (Salix nigra). The mid-story is composed primarily of boxelder (Acer negundo), and red maple (Acer rubrum). Several sloughs cross the area and baldcypress (Taxodium distichum) is the predominant species in these areas. Understory vegetation on the area is mainly composed of herbaceous plants and poison ivy vines. The site is subject to irregular flooding in the late spring and early summer. Some low lying portions of the stand are flooded annually in the winter and early spring with standing water remaining on those areas until the beginning of the growing season.

### Plot Selection and Establishment

An initial ground cruise of the area was used to determine the useable portion of the area for this study. Twenty 1.0 ha circular treatment plots were established on relatively homogeneous areas within the stand. At the time of establishment the interior 0.25 ha circular central portion of each plot was designated as the measurement plot. The larger trestment plot area served as a buffer from adjacent plots. Once plot locations and boundaries were established, basal area, density and species composition was determined for each plot for all trees equal to or greater than 10 cm in dbh. During the winter of 1983-84 thirty 1-0 bare-root seedlings (from the Louisiana Office of Forestry Nursury) of baldcypress, green ash (Fraxinus pennsylvanica), Nuttall oak (Quercus nuttallii), water oak (Q. nigra) and sweet pecan (Carya illinoensis) were planted on each measurement plot following a modified Nelder plot design. The planting design consisted of 15 equally spaced planting spokes radiating from the center of each plot. Ten seedlings of a single species were planted at a 3.0 m spacing along a spoke and each species was replicated on 3 such spokes of each plot.

### Harvesting Design

After one growing season in the field, the treatment plots were scheduled for partial overstory removal. Five overstory removal treatments consisting of a 30, 45, 60, 75 and 100 percent basal area removal were randomly assigned to the plots. All treatments were replicated four times. Trees marked for commercial harvest were primarily sawtimber size trees of cottonwood, black willow, baldcypress and sycamore. Mature and overmature cottonwood and willow represented 87 percent of the commercial harvest. Cull trees and trees of non-commercial value were then felled until the desired level of overstory removal was attained. Trees to be felled were marked so that the remaining basal area was relatively evenly distributed across each plot. Boxelder and red maple made up the majority of the non-commercial species cut. Logging took place from April through September of 1985 and consisted of chainsaw felling and tree length skidding of trees to landings. Landings and skid trails were not designated and no special precautions were taken to avoid measurement plots during the logging operation. Although skid trails were not designated, primary skid trails developed naturally and became the areas of most frequent travel.

### Measurements

Height, root collar diameter and damage by cause were recorded for all underplanted seedlings initially and at the end of each growing season. Cause of damage was segregated into several categories including, mortality by natural causes (low seedling vigor, poor planting or micro-site conditions, and animal damage) and logging related damage (skidder damage, felled tree or slash, located on a deck or landing). If a seedling was present before logging and missing after logging, evidence of the cause was ascertained by visual appearance at the seedlings previous location. This method of damage assessment may have caused some errors in assignment of cause of damage and may have led to an overestimation of logging related damage. Since final growth measurements for this paper were taken only a few months after harvest activities were concluded, differences among overstory treatments were not analyzed. It is unlikely that sufficient time had elapsed for treatment effects on growth to have taken place. Results are thus a composite analysis of the data.

## RESULTS AND DISCUSSION

### Survival and Causes of Mortality

Survival during the first growing season after outplanting was relatively high for all species (94.1 percent). First year survival ranged from a low of 87.8 percent for sweet pecan to a high of 98.7 percent for baldcypress (Table 1). After harvest (end of the second growing season) survival had declined considerably, but was still adequate for bottomland hardwoods. Survival after two growing seasons in the field averaged 64 percent and ranged from a low of 50.3 percent for baldcypress to a high of 74.2 percent for green ash (Table 1).

Mortality during the first growing season in the field was largely caused by animal damage, however, some seedlings did succumb because of low seedling vigor, poor planting technique and micro-site conditions. During the second growing season, continued animal damage and harvest related activities led to additional mortality. Mortality from animal damage and other natural causes led to a two year total

Table 1. First- and second-year survival of five pre-harvest planted bottomland hardwood species.

| Species | First-Year Survival | | Second-Year Survival | |
|---|---|---|---|---|
| | n | percent | n | percent |
| Sweet Pecan | 527 | 87.8 | 317 | 52.8 |
| Green Ash | 589 | 98.2 | 445 | 74.2 |
| Baldcypress | 592 | 98.7 | 302 | 50.3 |
| Water Oak | 548 | 91.3 | 414 | 69.0 |
| Nuttall Oak | 567 | 94.5 | 431 | 71.8 |

mortality averaging 16.8 percent. The highest mortality from these natural causes was associated with baldcypress and sweet pecan (26.5 and 23.8 percent respectively). Green ash was the least affected species with only 9.2 percent of the seedlings being destroyed by natural causes (Table 2). Logging related mortality was somewhat more evenly distributed across the planted species. Logging caused mortality averaged 19.6 percent and ranged from a low 16.7 percent for green ash to a high of 23.3 percent for sweet pecan (Table 2).

Table 2. Mortality by cause for five pre-harvest planted bottomland hardwood species.

| Species | Natural Mortality | | Logging Related Mortality | |
|---|---|---|---|---|
| | n | percent | n | percent |
| Sweet Pecan | 143 | 23.8 | 140 | 23.3 |
| Green Ash | 55 | 9.2 | 100 | 16.7 |
| Baldcypress | 159 | 26.5 | 139 | 23.2 |
| Water Oak | 80 | 13.3 | 106 | 17.7 |
| Nuttall Oak | 66 | 11.0 | 103 | 17.2 |

## Height Growth

Height growth of all species was relatively slow. Green ash and Nuttall oak grew the most rapidly, averaging 30.7 and 25.5 cm respectively. However, slow initial height growth is common among most moderately tolerant tree species and is not generally expected to increase rapidly for the first three to five years after planting. Baldcypress the most intolerant species planted was so heavily damaged by animals (main stems were clipped off a few cm above ground-line) that accurate estimates of its potential height growth could not be determined. Average height for baldcypress after two years in the field was 0.8 cm less than when it was planted. Mean height for all species was reduced by animal browsing or clipping of the main stem (Table 3). The mean height for undamaged seedlings exceeded the overall mean seedling height by 20.0 cm.

One way of predicting future success of regeneration is to establish a "target" seedling, a seedling of sufficient size to successfully compete and to attain a dominant or codominant position in the stand at maturity. A target size should be set based on data taken in the early years of stand development and a tracking of their success at some specified time later in the rotation. However no long-term studies exist for pre-harvest planting conditions in bottomland hardwood stands. We therefore arbitrarily set 1.0 m as a potential target size for initial comparisons of success for the study species. As shown in table 3 only Nuttall oak and green ash had substantial numbers of seedlings reaching or exceeding the specified target size (30.2 and 38.7 percent respectively). Sweet pecan was the poorest performer with only 1.3 percent of the surviving seedlings reaching the target height after two years in the field.

Table 3. Seedling height and percent exceeding target size two years after outplanting.

| Species | Overall Mean Height | Mean Height of Undamaged Seedlings | Seedlings Greater than 1.0 m tall |
|---|---|---|---|
| | cm | cm | percent |
| Sweet Pecan | 39 | 47 | 1.3 |
| Green Ash | 85 | 101 | 38.7 |
| Baldcypress | 55 | 82 | 6.6 |
| Water Oak | 60 | 79 | 11.4 |
| Nuttall Oak | 78 | 94 | 30.2 |

## CONCLUSIONS

Survival of pre-harvest planted bottomland hardwood seedlings after two growing seasons in the field averaged an acceptable 64 percent. Natural mortality, which was principally related to animal damage averaged less than 17 percent. Logging caused mortality was less than 20 percent overall and occurred mainly along primary skid trails and at log decks or landings.

Early height growth was slow as is common for planted seedlings of moderately tolerant bottomland hardwood species. Height growth can probably be expected to increase significantly after three to five years in the field if the planted seedling can maintain a competitive position within the stand. Baldcypress height growth was severely limited by rabbit damage and deer browse. Successful establishment of baldcypress by pre-harvest planting would almost certainly require protection from such damage. Target heights need to be established to allow prediction of regeneration success of various bottomland hardwoods from early measurements. An arbitrarily chosen height of 1.0 m was used for comparison of species in this study. Only Nuttall oak and green ash had a large number of seedlings reaching the target size. Species like sweet pecan, however, may not normally be expected to reach this height in high numbers even under more intense management regimes.

Therefore, long-term results tracked from early height measurements will be necessary for future prediction of regeneration success. Although early results seem promising, long-term results are necessary before pre-harvest planting can be recommended as an appropriate regeneration method on an operational basis.

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# Cherrybark Oak Enrichment Plantings Appear Successful After Seven Years in South Carolina Bottomlands[1]

L. E. Nix and S. K. Cox[2]

ABSTRACT.--After seven growing seasons, enrichment plantings of cherrybark oak on bottomland tracts in South Carolina appear to be doing surprisingly well. Two-year-old bare root seedlings were planted in clearcut and shelterwood cut blocks with preharvest disking and postharvest herbicide competition control. Seedling survival is highly variable, ranging from 20 to 79 percent, with privet hedge providing the most severe competition. Seedling size is highly variable, ranging from 0.2 to 6.6 inches in ground line diameter and 3 to 26 feet in total height. Preharvest disking with clearcutting gave the best diameter and height growth, 2.3 inches and 16 feet, respectively, and by far the best survival, 79 percent. Seedlings released during the second growing season with directed herbicide application (2% glyphosate) showed no better growth or survival than unreleased seedlings. The poorest treatment was the shelterwood without disking as competing vegetation continued to flourish after overstory removal. Privet, honeysuckle, spice bush and vigorous stump sprouts are providing tough competition where present, but many seedlings are now free-to-grow saplings and are growing 3-4 feet per year as is characteristic of cherrybark oak in a fertile bottomland after 6-7 years.

## INTRODUCTION

The oaks (Quercus spp.) are one of the most valuable components of the North American hardwood forest, both upland and lowland. In the South over half of the hardwoods harvested are from bottomland stands (Linde 1980) and oaks are an appreciable portion of the quality material that is harvested. Past forest use practices such as indiscriminate livestock grazing and highgrading have reduced the potential for quality natural regeneration in many bottomland hardwood stands. Current regeneration practices in bottomland stands are not consistently providing a quality oak component (Johnson 1979). In the absence of advanced oak reproduction or adequate oak sprouting, bottomland hardwood stands, formerly containing an valuable oak component, are regenerating to fast-growing, light-seeded species after clearcutting. Many bottomland sites capable of supporting vigorous oak growth no longer have a major component of oak in the overstory.

Artificial regeneration of oaks, such as intensively cultivated plantations, is feasible in only a few situations where intensive early management is economical. Only 12 to 15 percent of the Coastal Plain hardwood forest area is suitable for such intensive culture (Linde 1980). An alternative approach to improving the oak component of bottomland stands may be to conduct enrichment plantings whereby oak seedlings are established under an overstory or partial overstory prior to harvesting the stand. The survival to maturity of 15-20 well-spaced oak trees per acre may provide an adequate quality sawtimber component (Johnson 1980).

The objective of this study is to evaluate the potential of oak enrichment plantings for improving species composition in bottomland stands where natural oak reproduction is inadequate. Additional objectives are to evaluate inexpensive competition control methods, such as preharvest disking, directed herbicide application and partial overstory removal. Early results of this study were reported by Nix, et al (1985). This report presents results of oak enrichment plantings after seven years in a South Carolina red river bottomland.

## MATERIALS AND METHODS

Two-year-old, nursery-grown bare-root cherrybark oak seedlings (Quercus falcata var. pagodifolia) were dibble-planted in a red river bottomland in Kershaw County, South Carolina. The seedlings were planted at 15 x 15 foot spacings in one-half of circular fifth acre plots established in a first bottom stand of 70-80 year-old elm, ash, hackberry, box elder, and sycamore with an understory of dense grass and scattered dense patches of switch cane and privet hedge as described by Nix, et al (1985).

Four treatment conditions, clearcut, shelterwood, and preharvest disking of each, were established as 5 acre blocks. Height, basal diameter and survival of planted seedlings were determined after 2 and 7 growing seasons. Measurements were also made of competing vegeta-

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tion. At the time of the initial measurements herbicide (glyphosate-2 percent) was direct-sprayed on competing vegetation in a 1 meter radius around 15 seedlings randomly chosen in each treatment block. The herbicide spraying was equivalent to about one quart per acre application rate. Growth of herbicide-released seedlings was compared to that of untreated seedlings paired by vigor class in the same block. Experimental design of the study is analogous to a completely randomized, split-plot design with plots serving as replications rather than blocks. The SAS General Linear Models Procedure was used for analysis (SAS 1985).

## RESULTS AND DISCUSSION

Survival of planted oak seedlings after seven years is highly variable, ranging from 20 percent in the undisked clearcut treatment to 79 percent in the disked clearcut treatment (Table 1). Seedling survival in the shelterwood

Table 1.--Survival of planted cherrybark oak seedlings after two and seven growing seasons in a South Carolina red river bottomland.

| TREATMENT[a] | | | |
|---|---|---|---|
| Clearcut | | Shelterwood | |
| -- Percent -- | | | |
| 49 (63) | | 38 (59) | |
| Disk | Not Disk | Disk | Not Disk |
| 79(86) | 20(40) | 45(79) | 30(39) |

[a]Value in parenthesis is percent survival after 2 years.

treatments averages 38 percent with only slight improvement due to preharvest disking (+ 15 percent). A comparison of seedling survival after 2 and 7 growing seasons indicates that the greatest loss (50 percent) occurred in the undisked clearcut block between the second and seventh years (Table 1). This loss is understandable considering the fierce competition that ensues after complete overstory removal in these fertile bottomland sites. Privet hedge (Ligustrum sinense ), spice bush (Lindera benzoin) and Japanese honeysuckle (Lonicera japonica) as well as numerous stump sprouts of overstory species, particularly box elder, green ash, and sycamore, provided strong, overtopping competition for the small cherrybark oak seedlings, which did not grow very rapidly for the first several years.

The appreciable loss in survival of seedlings in the disked shelterwood treatment between the second and seventh year, a reduction from 79 to 45 percent survival (Table 1), may have been primarily due to the logging activity during the removal of the shelterwood overstory. Eighty-two percent of the seedlings lost were found to be located in skid trails or debris piles near a loading deck. This high loss may not be typical of a shelterwood treatment as plot location inadvertently occurred near and along old skid trails that were reused during the shelterwood overstory removal. An increased number of seedling plots in the study area might have resulted in a reduced proportionate loss of seedlings during the residual shelterwood removal.

Oak seedling mean ground line diameter did not differ between clear cut and shelter wood treatments, but the disked clearcut treatment groundline diameter was significantly greater than that of other treatments (Table 2).

Table 2.--Mean ground line diameter and height of planted cherrybark oak seedlings after seven growing seasons in a South Carolina bottomland.

| TREATMENT[a] | | | |
|---|---|---|---|
| Clearcut | | Shelterwood | |
| -- inches -- | | | |
| 1.9(15.0) | | 1.6(11.2) | |
| Disk | Not Disk | Disk | Not Disk |
| 2.3(15.8) | 1.2(13.4) | 1.7(11.2) | 1.5(11.2) |

[a]Values in parenthesis are seedling total height in feet.

This difference in ground-line diameter indicates a significant reduction in competition due to the preharvest disking, but only in the clearcut treatment, as disking seems ineffective in improving diameter growth in the shelterwood treatment.

Mean total height of planted oak seedlings is greatest in the disked clearcut treatment where seedlings average nearly 16 feet in height (Table 2). As with groundline diameter preharvest disking appears to improve height growth of planted oak seedlings in the clearcut treatment while the residual shelterwood overstory significantly reduces height growth, even when preharvest disking is done. Since survival interacts with seedling size to determine the real success of planting, seedling volume per acre was calculated as a stocking factor (Table 3). Mean volume of seedlings per acre is more than 3 times greater in the clearcut treatment than in the shelterwood treatment, but this difference is almost entirely due to the effect of preharvest disking on survival of planted oak seedlings in the clearcut area.

Disking might have had a similar beneficial effect in the shelterwood treatment had not so many seedlings been lost to logging damage during the residual overstory removal. This supposition is supported strongly by the data of Table 4 which show a significant reduction in the height of competing woody vegetation in the disked shelterwood treatment but not in the disked clearcut treatment.

Table 3.--Volume per acre of planted cherrybark oak seedlings after seven growing seasons in a South Carolina bottomland.

| TREATMENT[a] | | | |
|---|---|---|---|
| Clearcut | | Shelterwood | |
| -- cubic feet/acre -- | | | |
| 21 | | 7 | |
| Disk | Not Disk | Disk | Not Disk |
| 39 | 3 | 10 | 3 |

[a]Seedling volume = 1/3 basal area x height.

Table 4.--Mean height and distance to nearest woody competitor of planted cherrybark oak seedlings after seven years in a South Carolina bottomland.

| TREATMENT[a] | | | |
|---|---|---|---|
| Clearcut | | Shelterwood | |
| -- feet -- | | | |
| 17.8(2.4) | | 14.7(3.1) | |
| Disk | Not Disk | Disk | Not Disk |
| 17.7(3.0) | 18.7(1.9) | 13.4(3.4) | 16.1(2.8) |

[a]Values in parenthesis are distance to nearest woody competitor.

The mean distance to nearest woody competitor (Table 4) also indicates that preharvest disking may be effective in reducing competition in both the shelterwood and the clearcut overstory treatments. Combined with the woody competitor mean height data in Table 4, mean distance to nearest woody competitor indicates that the disked shelterwood treatment is most effective in reducing the competition of the planted oak seedlings. Unfortunately the loss of seedlings to logging damage has likely rendered these results inconclusive as the few remaining oak seedlings in the shelterwood treatment show a reduction in height growth of nearly 4 feet (Table 2), although they were under the shelterwood overstory for only two years.

In addition to woody competition near the oak seedlings the stocking of naturally regenerated woody species was also determined on 1/100 acre plots at the center of each fifth acre plot. Treatments appear to have had a significant effect on the natural regeneration in the study area (Table 5).

Table 5.--Stocking of naturally regenerated woody species after seven growing seasons in a South Carolina red river bottomland.

| | TREATMENT | | | |
|---|---|---|---|---|
| Species | Clearcut | Clearcut + Disk | Shelter-wood | Shelter-wood + Disk |
| | (Overstory Stems Per Acre) | | | |
| Ash | 75 | 425 | 50 | 425 |
| Bxe | 450 | 775 | 600 | 725 |
| Syc | 25 | 125 | 50 | 50 |
| Misc | 25 | 100 | -- | 375 |
| Total | 575 | 1425 | 700 | 1575 |
| | (Understory Stems Per Acre) | | | |
| Misc[a] | 2400 | 1175 | 3950 | 850 |

[a]Miscellaneous understory species are privet and spice bush.

Desirable green ash saplings were increased nearly 6-fold by the disking treatment in both the shelterwood and the clearcut areas. Sycamore saplings were increased 5-fold by the disking but only in the clearcut area. Miscellaneous overstory species, which were elm, hackberry, and China berry, were also greatly increased by the disking treatment. A contributory factor to these desirable species stem increases due to disking is probably the pronounced reduction in the dense grass root mat and in competing understory stems (primarily privet and spice bush). The disking resulted in a 51 percent reduction in understory stems in the clearcut area and a 78 percent reduction in the shelterwood area (Table 5). Although boxelder, an undesirable overstory species, was slightly increased by the disking, the disking has at least substantially increased the desirable species stocking, including that of the planted cherrybark oak seedlings.

Assuming no further mortality there will be an average of about 40 cherrybark oak saplings per acre in the undisked clearcut area and nearly 160 per acre in the disked clearcut area (based on the

simulated planting density of 200 seedlings per acre). There will be 60-90 oak saplings per acre in the shelterwood areas. The cherrybark oak saplings average only 2 to 3 feet less in height than the nearest woody competitors and have begun to grow rapidly with many saplings now in a free-to-grow condition. Based on recent research results cherrybark oak becomes a vigorous competitor if it can just persist for four to five years (Krinard and Francis 1983; Johnson 1984). The most severe competition in the study plots is from privet and spice bush which is approaching its maximum height. The cherrybark oak saplings are now in their period of maximum height growth and should rapidly grow out of the understory competition, especially those in the disked treatment areas.

Many sprouts on larger boxelder and green ash stumps (> 20 inches diameter) are dying or appear to be losing vigor, thus reducing overtopping competition. Many of the planted oak saplings in the undisked areas appear spindly and weak, especially where privet has completely overtopped them. Privet is a severe competitor for the small planted oak seedlings and, even after disking, vigorously resprouts to quickly overtop planted seedlings. The fate of these overtopped seedlings is very much in doubt based on their current appearance. Post harvest herbicide spraying, as done in this study, did not provide effective nor long-lasting release for the planted seedlings. Although it appeared to improve survival after two years, herbicide application actually reduced height growth and had no significant effect on growth or survival of planted oak seedlings after seven years. However, herbicide may have an important role in enrichment plantings in other areas as a parallel study under different conditions showed the effects of herbicide release were still detectable after six years (Nix, unpublished data).

## CONCLUSIONS

The results of this study indicate that species composition of bottomland stands can be enriched by planting quality species, such as cherrybark oak, and that preharvest competition control, such as disking, can improve survival and growth of planted stock significantly. Although the shelterwood overstory treatment did not improve seedling growth or survival, the disproportionate loss of seedlings from logging activities may have biased the results of this part of the study. The shelterwood treatment reduced the growth of both planted seedlings and their competition resulting in about the same differential in height as in other treatments.

The shelterwood disked treatment significantly reduced the number of competing understory stems per acre and increased the number of desirable overstory stems equally as well as did the clearcut disked treatment. Thus, the shelterwood should not be rejected as a potential overstory treatment for enrichment plantings.

Other practical preharvest competition control methods should be explored as the disking treatment used in this study may not be feasible in bottomland stands with different stand structure. In addition no attempt was made to do an economic analysis of any of the treatments in this study. Costs of hand planting, preharvest disking, post harvest herbicide application and other treatments mentioned will have to be offset by the increased value of the oak component in the stand at rotation end.

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STUDIES ON THE BIOLOGY OF CHERRYBARK OAK: RECOMMENDATIONS FOR REGENERATION[1/]

John D. Hodges and Greg Janzen[2/]

Abstract.--A review of past efforts to regenerate this species indicates that the ecological requirements of the species have not been adequately considered. Advance regeneration (number and size) is essential for natural stand regeneration. Results of several recent studies of the light requirements for regeneration, growth and development in mixed stands, and influence of midstory and understory on seedling establishment and development indicate that control of light to the forest floor is the key to obtaining adequate advance regeneration. Too much light may be as detrimental as too little in that it will favor growth of faster growing, more intolerant species. It is suggested that several techniques (shelterwood method, midstory and understory control, shelterwood plus control of lower stories, enrichment plantings) may be used to regenerate oak stands and that the choice should be based on a thorough analysis of the stand conditions.

## INTRODUCTION

Cherrybark oak (Quercus falcata var. pagodafolia) is one of the most desirable tree species in the South. Its good growth rate, straight clear stems, and large size make it valuable for timber production (Putnam et al. 1960). In addition, the quantity and quality of mast production makes it highly desirable for wildlife (Lotti 1965).

The major silvicultural problem with cherrybark oak is during regeneration. There are indications that oaks, and particularly cherrybark, are not being satisfactorily regenerated after the final harvest (Johnson and Krinard 1976). The primary reason for oak regeneration failures seems to be an insufficient number and/or size of advance oak seedlings at the time of harvest (Beck 1970, Johnson 1975, Sander 1977). Size is of critical importance in that small seedlings simply are not able to compete successfully with stump and root sprouts of some species and very fast growing seedlings of other species (Johnson 1979). A height of 4.5 feet is considered minimal for advance growth of northern red oaks (Sander 1972) and a similar height seems desirable for cherrybark oak.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2/] The authors are professor and research technician, Department of Forestry, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University. Contribution No. 6528 of the Mississippi Agricultural and Forestry Experiment Station.

Some of the problems associated with natural regeneration of cherrybark oak may be alleviated by use of artificial regeneration, but there are major problems with this alternative. Survival is usually very good, but as with natural regeneration, slow early growth is a severe problem. Intensive control of competing vegetation, usually by cultivation, is necessary and expensive. Thus the cost of artificial regeneration is prohibitive for most landowners.

This paper reviews some of the past and current research efforts and cultural practices dealing with cherrybark oak regeneration, discusses seedling ecology in relation to these practices and current research efforts, and suggests recommendations for cherrybark oak regeneration. Most of the discussion is specific for cherrybark oak, but the results should be applicable to the other bottomland red oaks as well as northern red oak.

## PAST REGENERATION EFFORTS

Artificial regeneration efforts have largely been directed at improving the early growth rate of outplanted seedlings to circumvent or alleviate the need for intensive competition control. The influence of nursery practices and container production on the early field performance of seedlings have been studied at this station. The results from several nursery studies (unpublished) indicate that seedlings of very acceptable size (2½-3 feet; 3/8+ inch root collar diameter) and vigor can be produced in one growing season provided that : (1) nursery density is about 10 per square foot or less, and (2) the seeds are sown early enough in the spring. In central Mississippi, it is desirable to seed

in early March, but no later than the first of April.

Root modification treatments in the nursery beds (undercutting and lateral root pruning) increase root proliferation, but the results, in terms of effect on seedling height growth, are inconclusive at this time.

Studies of containerized seedlings of cherrybark oak and other bottomland red oaks (Moorhead 1978, 1981) have shown better initial height growth than for bare-root material of the same age. However, the difference in growth is not great enough to eliminate the need for competition control, and the cost per seedling is much greater for those grown in containers. There may be some advantages of containerzied seedlings but the economics of use have not been determined.

Past efforts with natural regeneration have dealt mainly with techniques for obtaining satisfactory advance oak regeneration. The techniques involved modifications of harvesting methods and concentrated primarily on use of the shelterwood method (Johnson 1979, Sander 1979, Loftis 1983). The shelterwood system has not been thoroughly tested with cherrybark oak, but the indications are that, as with other red oaks, classical shelterwood cuttings will not give satisfactory advance oak regeneration. Possible reasons why it has not been successful will be discussed later.

## SEEDLING ECOLOGY IN RELATION TO PAST AND CURRENT REGENERATION EFFORTS

The above brief review indicates the problems we have with cherrybark oak regeneration and demonstrates the need for more effective mthods of regeneration. More importantly, it emphasizes the need for a better understanding of the biological requirements of the species. In essence we have put the "cart before the horse" by researching methods of regeneration without a sufficient knowledge of the biology of the species. Much of our current research effort at Mississippi State is designed to learn more about the ecological requirements of cherrybark oak.

Two aspects of seedling biology which are very important in regeneration are light requirements for maximum grown and juvenile growth rates. Two current studies involve investigation of light requirements and methods for manipulating light for cherrybark oak reproduction. In one study, oak seedlings have been grown for two years from seed under shade houses with light intensities of 100, 53, 27, and 8 percent of full sunlight. Results demonstrate that cherrybark oak seedlings do not require a high light intensity for good growth (Table 1). Best development occurred at about 50% of full sunlight and even at 27% of full sunlight height growth was better than under open conditions. However, caution must be

Table 1.--Effect of shade on growth of cherrybark oak seedlings at the end of the first and second growing seasons.

| % Shade | Year 1 | Year 2 | Year 2 Growth |
|---|---|---|---|
| | ----------$\bar{x}$ ht (cm) | ---------- | ---------- |
| 0 | 21.4 b[1/] | 45.0 b | 25.4 b |
| 47 | 28.3a | 86.0a | 59.2a |
| 73 | 22.4 b | 71.5a | 47.7a |
| 92 | 18.7 b | 36.2 b | 15.4 b |

[1/] Values in a column that are followed by the same letter indicate no statistical difference at the .05 level.

exercised in extropolating these results to field conditions. The shade cloth changed only the intensity of light reaching the seedlings, but light beneath a stand is changed in both intensity and quality (wave length). Also, there is likely a difference between the field and shade houses in terms of the interaction between light and moisture availability. It was obvious that soil moisture depletion occurred more rapidly in the open than beneath the shade houses.

Observations in numerous older stands where oak regeneration was not present suggested that the problem was insufficient light on the forest floor. Very often insufficient light was due to the presence of a very dense midstory and understory, usually of less desirable species such as American hornbeam (*Carpinus caroliniana*) and eastern hophornbeam (*Ostrya virginiana*). Therefore, a study was undertaken to determine how removal of this material would influence oak seedling establishment and growth (Janzen and Hodges 1985). The following treatments were installed: (1) *Inject only*. All trees of undesirable species greater than 1.0 inch d.b.h. and that did not contain at least one number three factory grade sawlog were injected with glyphosate. (2) *Inject/spray*. Inject as above combined with foliar spraying with glyphosate of remaining stems (including desirable species) and vegetation which could be reached with a backpack sprayer (height of approximately 10 feet). *(3) Control*. Midstory and understory left intact. After treatment it was obvious that much more direct sunlight could reach the forest floor and after five years there is a significant improvement in oak regeneration in terms of both numbers and seedling size (Tables 2 and 3).

Even though oak advance regeneration is present it may be very slow to develop in

Table 2.--Effect of midstory and understory control treatments on number of oak seedlings present five years after treatment.

| Treatment | Red | White | Total |
|---|---|---|---|
| Inject | 2047a[1/] | 1263a | 3310 |
| Inject/Spray | 1873a | 915a | 2788 |
| Control | 653 b | 348a | 1001 |

[1/]Values in a column followed by the same letter indicate no significant difference at the .05 level.

mixed hardwood stands even after a complete removal cut (Beck 1970, Johnson 1975, Sander 1977), and this may be as much of an overall problem as lack of advance regeneration (Johnson 1979). A recent study examined cherrybark oak development in even-aged mixed stands comprised primarily of oak and sweetgum (Clatterbuck et al. 1985). Individual stem development of the two species was observed in 160 plots which varied in age from reproduction to about 80 years. The plots were located primarily on old field sites. In 35 of the 160 plots oak and sweetgum trees were felled and subjected to a detailed stem analysis of radial and vertical growth patterns. Cherrybark oak exhibited two patterns of height development depending on the spacing between the oak and competing sweetgum. The "restricted" pattern (Figure 1) of development occurs when the average spacing between trees is about 18 feet or less at the pole stage. The cherrybark oak initially grows slower than the sweetgum, but if it can get some direct sunlight it will eventually outgrow and stratify above the sweetgum at age 20 to 25. A similar pattern of development has been noted for cherrybark oak after a complete clearcut

Table 3.--Effect of midstory and understory control treatments on size of oak regeneration 5 years after treatment.

| | Oak Stems/Acre > 20 cm ht | | |
|---|---|---|---|
| Treatment | Red | White | Total |
| Inject | 479a[1/] | 479a | 958 |
| Inject/Spray | 653a | 305a | 958 |
| Control | 44 b | 87a | 131 |

[1/]Values in a column followed by the same letter indicate no statistical difference at the .05 level.

(Johnson and Krinard 1983). The "unrestricted" pattern (Figure 2) occurs when cherrybark oak is either a few years older than the sweetgum or is essentially open grown. Diameter growth rates are much better for oak trees with the unrestricted pattern of development, but the restricted pattern produces trees with more clear wood and a much greater merchantable height.

Figure 3 is an attempt to portray the relationship between cherrybark oak and various competitor species in terms of light requirements and juvenile growth rates. The concepts presented were derived from the results of the above studies as well as years of field observation. Placement of the species indicates relative relationships. Exact values are not known at this time. The differences between species apparently reflect differences in efficiency of light utilization at different intensities for net primary production, especially as reflected in height growth.

The figure and available data indicate that under open conditions (high light intensity) cherrybark oak is not a good competitor when compared to fast-growing species such as yellow poplar (Lirodendron tulipifera). On the other hand, cherrybark oak is a persistor. It is able to survive and grow at light intensities which are far too low for most species which have a fast juvenile growth rate at high light intensities. At very low light intensities cherrybark oak can not compete with the very tolerant species such as American hornbeam and eastern hophornbeam.

The above ecological considerations have implications in designing or choosing silvicultural methods for the regeneration of cherrybark oak. The key to success, especially for natural regeneration, is in regulation of the light to the forest floor. For cherrybark and other red oaks, past regeneration efforts where adequate advance reproduction was not present have emphasized use of cutting modifications such as the seed tree or shelterwood methods rather than clearcutting. Use of the seed tree method is completely ineffective for increasing oak regeneration (DeBell et al. 1968, Johnson and Krinard 1983) and use of classical shelterwood methods have been erratic and mostly unsuccessful (Sander 1979, Loftis 1983, Martin and Hix 1986). Lack of success with the shelterwood method appears to be due to the way it is used. In the way it is most often used, trees are removed from the upper canopy leaving about 30 square feet of basal area if a two-cut shelterwood is used and about 60-70 square feet after the first cut of a three-cut shelterwood. Cuttings that heavy will favor the growth of fast-growing intolerant species such as yellow poplar rather than red oaks (Loftis 1983) especially if little or no lower story species are present. A series of

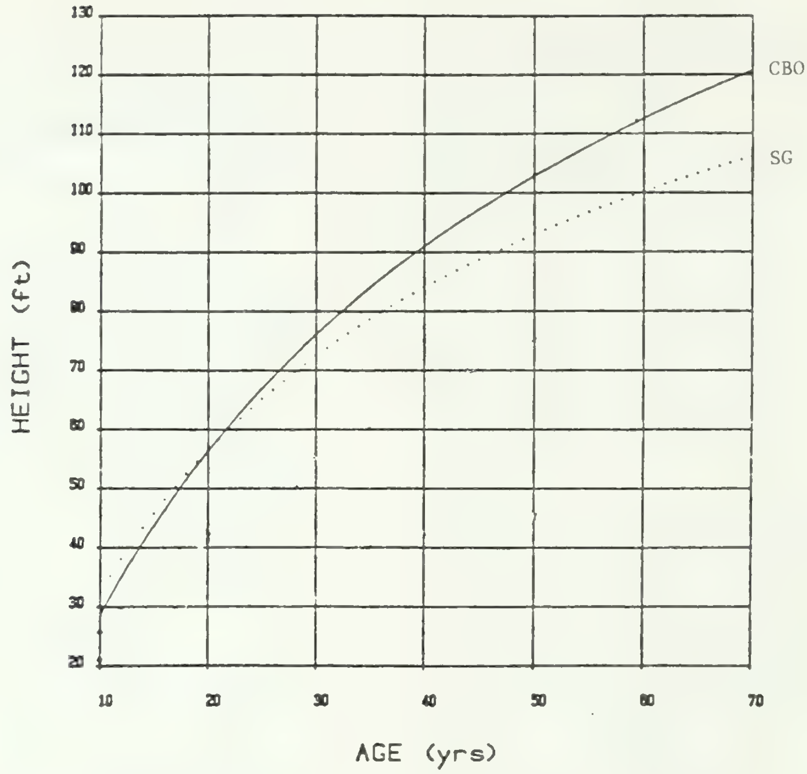


Figure 1.--Cumulative height-age curves for dominant and codominant cherrybark oak (CBO) and sweetgum (SG) in stands with the restricted pattern of development.

cuttings much lighter than normally used for a shelterwood might be used in such cases to regenerate red oaks (Loftis 1983). On the other hand, if there is a dense midstory and understory of tolerant species, as there often is in bottomland hardwood stands, then no amount of cutting in the overstory will give good oak regeneration (Janzen and Hodges 1985). There will simply not be enough light on the forest floor and the cutting will stimulate growth of the tolerant midstory.

Past efforts at artificial regeneration have largely ignored natural seedling ecology. On recently harvested sites, even with site preparation, the nursery-grown seedlings are forced into a competitive position for which they are not adapted. Under these open conditions, brush, sprout material, and seedlings of fast-growing intolerant species will simply outgrow the oaks. Thus, it has been necessary to use intensive and rather expensive cultural practices such as cultivation to control the faster-growing competition.

## REGENERATION STRATEGIES

Cherrybark oak can be regenerated artificially by planting or direct seeding and under some circumstances this may be the best option. This is especially true on sites which can be direct seeded (Johnson and Krinard 1985). However, on most sites and for most landowners the cost of artificial regeneration is prohibitive. As with other bottomland hardwoods, natural regeneration techniques will be of primary importance for the foreseeable future (Kellison 1985).

When natural regeneration methods are to be used, the first step should be a detailed evaluation of site and stand conditions to determine the potential for successful regeneration. Evaluation methods such as those proposed by Sander et al. (1976), Johnson (1980), and Marquis and Bjorkhom (1982) can be used. They are based on the number and size of advance regeneration stems as well as stump sprout potential and can be used to evaluate regeneration potential for a single species or for all species. If the regeneration potential is adequate the stand can be regenerated by a complete removal of all stems above one inch in diameter. When the regeneration potential is not adequate the task becomes one of securing enough advance regeneration before the final harvest. There are a number of options which will work, but they are site and stand specific so it is extremely important to match the recommendation to the stand. The following is

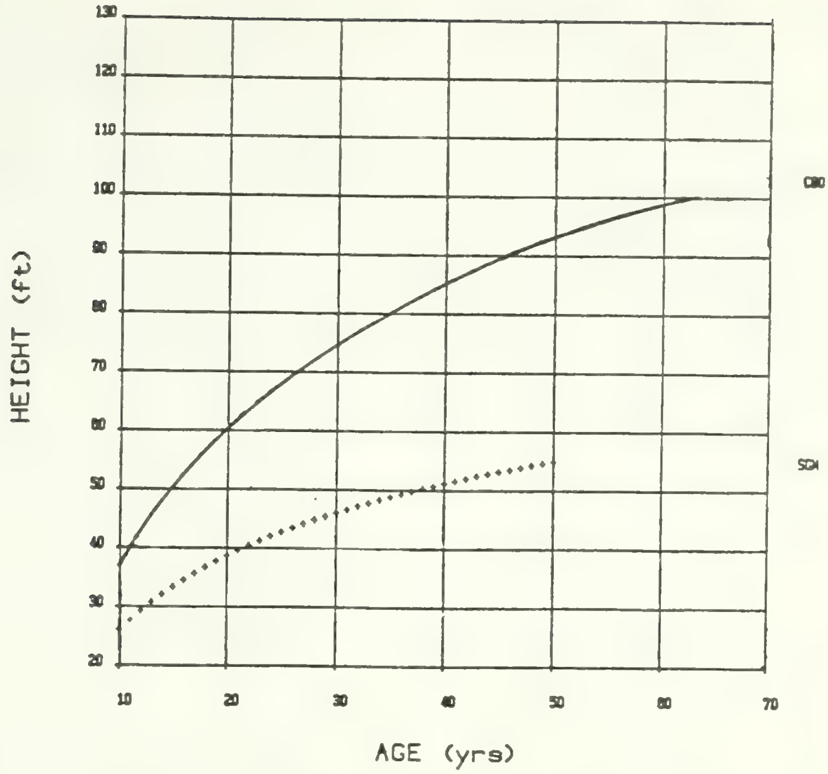


Figure 2.--Cumulative height-age curves for representative trees of both cherrybark oak (CBO) and sweetgum (SG) in stands with the unrestricted pattern of development.

a list and brief description of some options which can be used:

Enrichment planting -- This option has been discussed by two other speakers at this conference (Chambers et al. 1986, Nix and Cox 1986) and involves supplementing natural regeneration by underplanting of seedlings several years before the final harvest. Some control of competition in the lower stories may be necessary. Direct seeding may be an even more attractive way to supplement natural regeneration. Direct seeding has been very successful in larger open areas (Johnson and Krinard 1985). Sowing beneath a canopy has worked on a few occasions, but in most cases the seeds are lost to rodents. Timing of the seeding may be important in preventing rodent depredation, but success will ultimately depend on the development of an effective rodent repellent.

Use of shelterwood method -- Classical shelterwood cuttings usually have not been successful in regenerating oaks, but as suggested by Loftis (1983) very light cuts over a period of years may work. Use of the method should be confined to stands without a dense midstory or understory. This technique has not been rigorously tested for cherrybark oak, but observations in stands which have received light partial cuts indicate that it may work.

Midstory and understory control -- The upper canopy of bottomland hardwood stands in the South is often quite open because of past cutting. However, light to the forest floor may be very low because of a dense midstory and understory of tolerant species and regeneration of oaks does not occur. Removal of these lower stories will greatly increase light to the forest floor and may be all that is necessary to obtain advance regeneration of oaks and other desirable species.

Shelterwood plus control of lower stories -- In some stands, cutting will need to be done in both the main canopy and lower canopies in order to get sufficient light for regeneration. This can be accomplished by a shelterwood cut combined with lower canopy control by injection or cutting. Care must be exercised not to open the stand too much (Loftis 1983).

The above discussion emphasizes the need for stand-specific methods for oak regeneration and describes some of the techniques which may be used. However, it must be emphasized that, at least for

Light Requirement for Maximum Growth →

IW SB ELM CBO SG SYC YP

increasing juvenile growth rates →

Figure 3.--Light requirements and juvenile growth of cherrybark oak in comparison with competitor species.[1/]

[1/] IW = ironwood; SB = sugarberry; ELM = elm; CBO = cherrybark oak; SG = sweetgum; SYC = sycamore; YP = yellow poplar.

cherrybark oak, the recommendations are presently tentative. More definitive recommendations must await the result of long-term studies now underway.

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# SYCAMORE COPPICE RESPONSE TO HARVEST SEASON: 7-YEAR TRENDS[1]

Kenneth R. Roeder[2]

Abstract.--Five season-of-harvest treatments (March, April, June, August and October) were imposed in 1979 on a 12-year-old sycamore (Platanus occidentalis L.) plantation on the Northern Coastal Plain of North Carolina. Resulting coppice response was evaluated annually for 7 years following harvest. The late dormant season harvest treatment (March) resulted in significantly taller and larger diameter sprouts than those cut at other times of the year. The rate of biomass accumulation was also significantly greater for the late dormant season harvest treatment coppice.

Season-of-harvest did not significantly influence the number of coppice sprouts per stump after the second growing season following harvest. Orginal tree DBH, used as a stump diameter index, had a significant influence on the amount of sprout biomass produced. Weed competition control appears to be just as important in successful coppice stand establishment as it is with hardwood seedling plantations.

Keywords: Sprout mortality, Biomass, Competition.

## INTRODUCTION

Asexual regeneration of hardwoods through the sprouting of stumps and roots (coppice) is a significant source of new growth in some naturally regenerated hardwood stands (Petruncio 1985). Coppice regeneration has been an integral component of forest management in some parts of the world for centuries (Rackham 1980), but has been seldomly utilized consciously for regenerating natural hardwood stands in the United States. The limited research efforts with coppice have shown that quality and yields of regenerated stands can be altered by knowledgeable use of coppicing (Buell 1940; Roth and Hepting 1943; Downs 1947; Sander 1971; Johnson 1975; Kennedy 1975; Stroempl 1983), through the silvicultural manipulation of those factors influencing coppice response (Lust and Mohammady 1973; Blake and Raitanen 1981). The factors include: species, fertility, spacing, season-of-harvest, weed competition, cultivation, physiology and internal chemical controls, rotation length, stump diameter, stump height, and stump mortality (Blake and Raitanen 1981).

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Significant influences have been reported for some season-of-harvest coppice studies (i.e.: Buell 1940; Wenger 1953; Grano 1955; Longhurst 1956). Research has shown that dormant season harvests result in more productive coppice growth than growing season harvests (Stoeckler 1947; Wenger 1953; Roeder and Hansen 1985). However, most season-of-harvest coppice studies report coppice response success at a single point in time and by the number of sprouts surviving at 1 to 4 years following the harvest cut (Blake and Raitanen 1981). Results reported by Roeder and Hansen (1985) on sycamore (Platanus occidentalis L.) indicate that a simple assessment of only the number of sprouts at a point in time may be inadequate for evaluating success of season-of-harvest coppice studies.

Recent market changes for hardwood biomass may make short rotation biomass plantations a viable economic alternative to meet fiber and fuel stock demands. However, compared to pine plantations, hardwoods have relatively high initial establishment costs and require intensive and expensive silvicultural treatments in order to become successfully established (Malac and Heeren 1979). Multiple cropping through the use of hardwood coppice from a single planting may provide the favorable economics necessary for just such a biomass production system.

Continued research into factors affecting coppice response and long-term productivity is therefore justified. The work reported in this

paper evaluates sycamore coppice response for a continuous period of 7-years following five seasonal harvesting treatments.

## MATERIALS AND METHODS

A 12-year-old sycamore plantation in Hertford County, North Carolina on a terrace of the Meherrin River was chosen as the study site, as an installation of the Coppice Project of the NCSU-Industry Cooperative Hardwood Research Program. The plantation, formerly a fertilizer-spacing-thinning study of Union Camp Corporation, was blocked to incorporate the fertilizer-spacing-thinning treatments. Seven soil series (Myatt, Goldsboro, Eunola, Johns, Suffolk, Kenansville and Wagram variant) were identified on the original study site (SCS 1980), but could not be fully incorporated in the blocks and were therefore considered part of random site variation.

Since the establishment of this plantation, more knowledge has been obtained on site requirements for hardwood species including sycamore and sweetgum (Liquidambar styraciflua L.) That knowledge would today favor the planting of sweetgum as a more productive and better matched species to this site. However, the sycamore on this site is viable for determining the effect of season-of-harvest coppice treatments.

Stocking of the sycamore plantation chosen for this coppice study ranged from 452 to 988 trees (stumps) per hectare, with a mean stocking of 795 trees per hectare. The five season-of-harvest treatments consisted of chainsaw harvesting the existing 12-year-old trees within the treatment plots at their designated harvest season--March 15, April 30, June 30, August 31 and October 31 in 1979. All trees were cut within 15 cm of ground line. The March harvest treatment was installed as a late dormant season treatment; the October harvest treatment as an early dormant season treatment; and the April, June and August harvest treatments as progression of growing season harvest treatments. The seasonal harvesting treatments, in four replications, were assessed during mid-dormant season (January) following harvest and in January of each of the following 7 years. Plots were 0.072 hectares in size in one replication and 0.036 hectares in all other replications.

Diameter at breast height (DBH) was measured on all study trees during the dormant season just prior to installation of the harvesting treatments. These diameters were used as a measure of the original tree's dominance in the stand; they also served as an indirect measure of the size and vigor of each root system, and will henceforth be referred to as stump diameter index (SDI). The SDI ranged from 4 to 19 cm. These SDI data were then used as a covariate adjustment of the coppice response variables under study. All analyses and values presented are adjusted for SDI.

The coppice regeneration was measured for total height and DBH of the dominant sprout per stump, and number and mean height of sprouts by 2.5 cm DBH class for each stump. Stocking levels were assessed as the number of coppice sprouts in each diameter class per stump and extrapolated to per hectare values. Only living sprouts were assessed.

Biomass for the coppice and the original sycamore stand was calculated, using equations for predicting total green biomass of understory soft hardwoods (Phillips 1981). These equations were chosen because no satisfactory biomass equations specifically developed for sycamore coppice were available and the ranges of diameters for the coppice and the original stand closely matched the data used to develop the equations. The calculated biomass is therefore used as an index for treatment comparisons. Biomass was evaluated as mean biomass per sprout and per stump. Biomass per hectare was used as a measure of total coppice productivity.

The data were analysed as a randomized complete-block design. Treatment responses were evaluated for each assessed variable annually using standard analysis of variance techniques (Steel and Torrie 1980). The productivity trends for each seasonal harvest treatment were evaluated by testing for heterogeneity of slopes for height, DBH, stocking and biomass productivity over the seven assessment years, and incorporated SDI as a covariate adjustment factor (Freund and Littell 1981). Significance is indicated at the .05 probability level.

## RESULTS AND DISCUSSIONS

### Stump Diameter Index

As a covariate, SDI was found to be significant for total sprout basal area per hectare, biomass per sprout and biomass per hectare. This result is supported by the findings of Belanger (1979), also with sycamore, and could be expected as basal area and biomass are highly correlated. No evidence was found to indicate a significant contribution of SDI to the number of coppice sprouts produced as has been reported elsewhere (i.e.: Mattoon 1909; Schrierbeck and Clarke 1984; Singh and others 1973), but this may be due to the more limited range of SDI found in the sycamore plantation. The influence of number of sprouts per stump is an important contributor to the total biomass produced per stump and is most likely the reason that SDI was not found to significantly contribute to biomass per stump.

### Sprout Mortality

By the end of the first growing season, some sprouts were lost to mortality due to within-stump sprout competition for the March, April and June harvest treatments (Figure 1). The August and October treatments appeared to be free of the severe within-stump sprout competition. By the end of the 2nd growing season, all treatments were past the point of supporting a maximum number of sprouts per stump as within-stump sprout competition was eliminating the smaller sprouts. Within any given year, significant differences in mean number of sprouts per stump due to seasonal harvesting treatments were undetectable after the 2nd growing

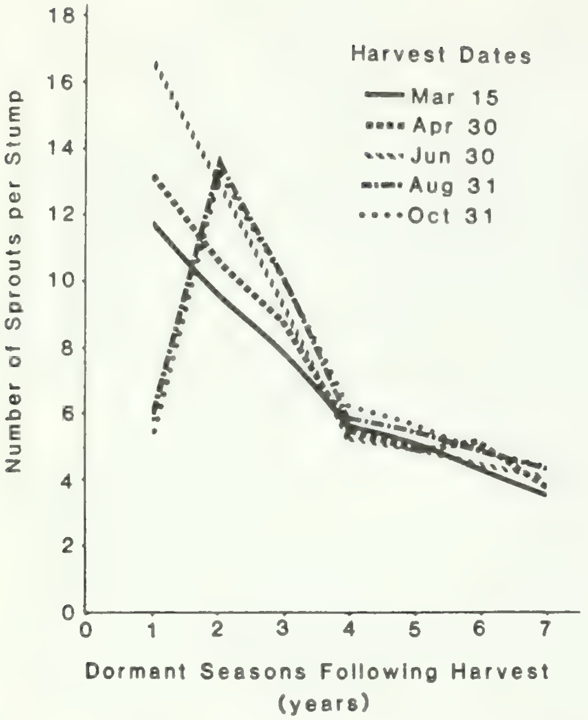


Figure 1.--Mean number of sycamore coppice sprouts per stump for 7 years following five seasonal harvest treatments.

season. A similar finding was reported by Wendel (1975) for Appalachian hardwoods.

In the period between the 2nd and 4th growing seasons, a significant difference in the within-stump mortality rate (slope) was detected (Figure 1). By the 4th growing season an equilibrium level in sprout survival was reached for all seasonal harvest treatments. The sprout mortality rates for the seasonal harvest treatments from the 4th through 7th growing seasons were not significantly different. Note that the sprout mortality which occurred in this study was due to within-stump sprout competition as stump spacings and overall growth was such that between-stump sprout crown competition was limited.

The mortality rate of sprouts per hectare closely mirrors that of mortality per stump due to the general uniformity in stump survival rate among the harvest treatments.

## Height

The dominant sprouts from the March harvest treatment are significantly taller than coppice resulting from the other harvest treatments through the 7th growing season (Figure 2). However, the rate of height growth is consistant for all treatments indicating that the advantage in dominant sprout growth obtained by the March harvest treatment is achieved in the first growing season and maintained at least through the 7th growing season.

The significant superiority of the March harvest treatment is also expressed in mean height of all coppice sprouts per stump for any given year (Figure 3). In addition, the rate of the mean sprout height growth is significantly greater for the March treatment. This significant difference in the reported rate of mean sprout height growth is the result of actual sprout height growth as well as within-stump coppice stand development. This coppice stand development occurred earlier in the March harvested plots as the result of the within-stump sprout competition eliminating the smaller intermediate and suppressed sprouts, thereby increasing the mean height of the surviving sprouts.

The period between the March 15 and the April 30 harvest treatments appears to have been critical to the growth potential of the resultant coppice. Cutting trees prior to mobilization of hormones and nutrients stored as carbohydrates in the roots (March harvest treatment) permits the potential for full availability of these nutrients for subsequent coppice response. Cutting after partial mobilization (April harvest treatment) results in a proportional reduction in the coppice response (Wenger 1953). The lowest level of nutrient reserves in the roots is prior to full leaf expansion (Alban 1985) which occurred before the June 30 cutting treatment in this study.

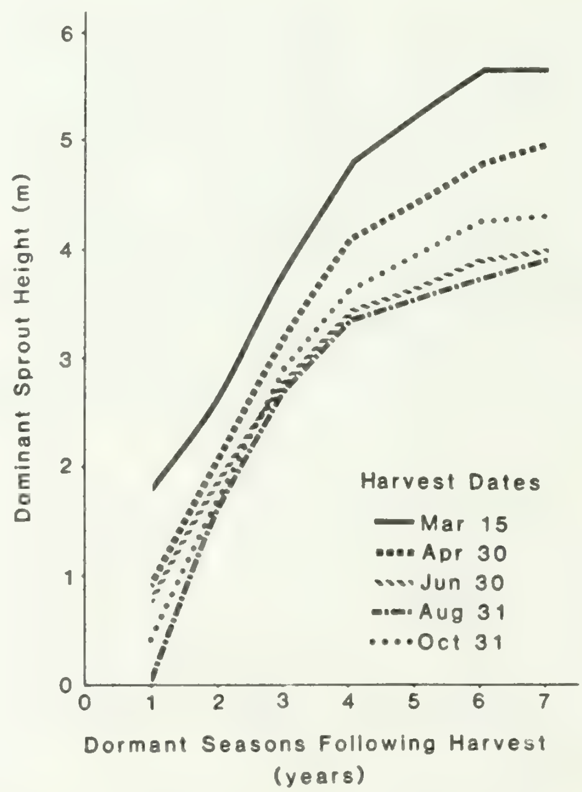


Figure 2.--Mean height of the dominant sycamore coppice sprout per stump for 7 years following five seasonal harvest treatments.

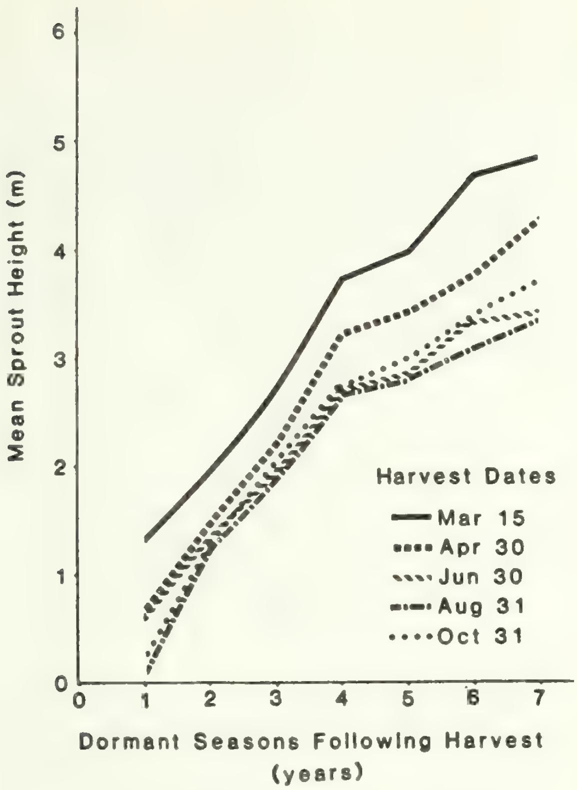


Figure 3.--Mean height of all sycamore coppice sprouts per stump for 7 years following five seasonal harvest treatments.

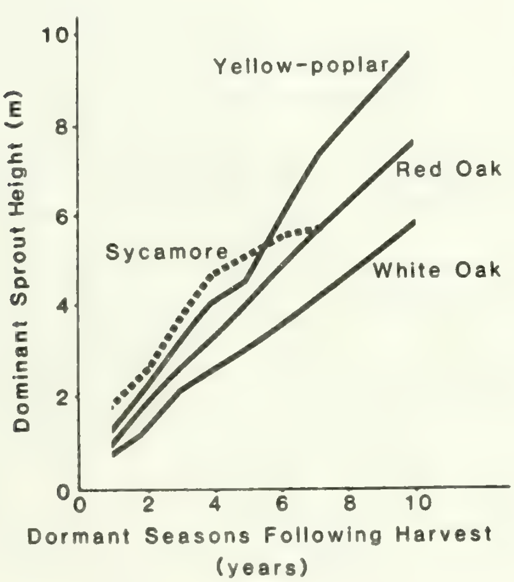


Figure 4.--Dominant coppice sprout height growth of dormant season harvests of Yellow-poplar, red oak, white oak (from Wendel 1975), and sycamore. (Note: species indentification of oaks only to subgenus level.)

The rate of dominant sprout growth of late dormant season harvested sycamore coppice was initially faster than that reported for dormant season harvested oak (Quercus sp.) and yellow-poplar (Liriodendron tulipifera L.) on excellent and fair natural stand sites (about 55-years-old) in West Virginia (Wendel 1975) (Figure 4), but appears to be decreasing by the 7th growing season. Yellow-poplar surpassed sycamore cumulative height growth during the 6th growing season, while red oak has caught up to sycamore by the end of the 7th growing season.

Diameter at Breast Height

Mean diameter growth of the dominant stump sprout from the March harvest treatment was significantly larger than the dominant sprouts from the other harvest treatments through the 7th growing season (Figure 5). The rate of diameter growth was also significantly superior for the March treatment. This superior diameter growth of the March treatment sprouts is a function of their earlier start at the beginning of the initial growing season following harvest treatment, earlier stand development and dominance expression of the competing sprouts within each stump. Once a sprout acquires a superior crown position in the within-stump sprout canopy, the sprout is able to maintain or expand its dominance as it suppresses smaller, slower growing sprouts.

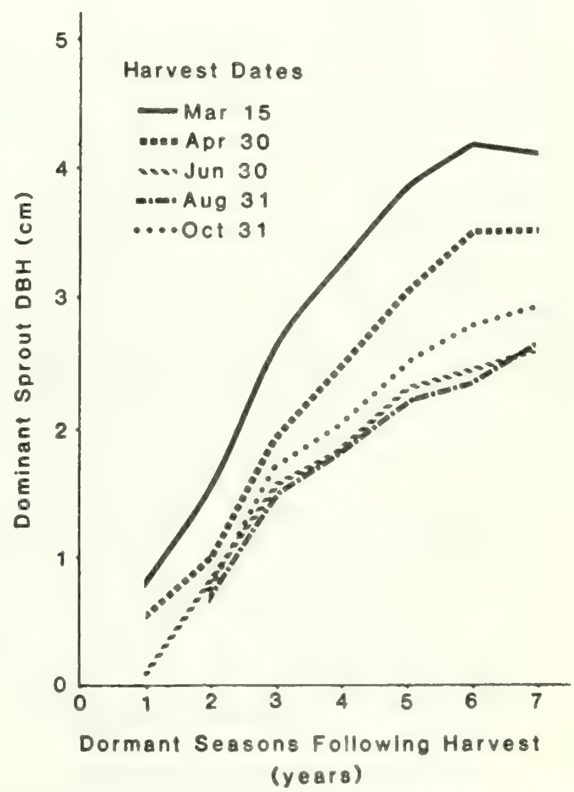


Figure 5.--Mean diameter at breast height of the dominant sycamore coppice sprout per stump for 7 years following five seasonal harvest treatments.

Mean sprout diameter growth reflected the same trends and relationships as for dominant sprouts (Figure 5). Overall, the rates of mean sprout diameter growth were less than that for dominant sprouts.

Biomass

The March harvest treatment consistantly produced significantly larger sprouts than the other season-of-harvest treatments. These sprouts, because of their larger size and inferred larger photosynthetic area, grew at a significantly faster rate than sprouts from other harvest treatments. Between the 6th and 7th growing seasons, the rate of biomass growth increment for the March harvest treatment declined (Figure 6). This decline was due to widespread vine competition, particularly in replication one of the study.

Honeysuckle (*Lonicera japonica* Thunb.) competition was so severe in some instances that the sprouts were physically damaged, the effects of

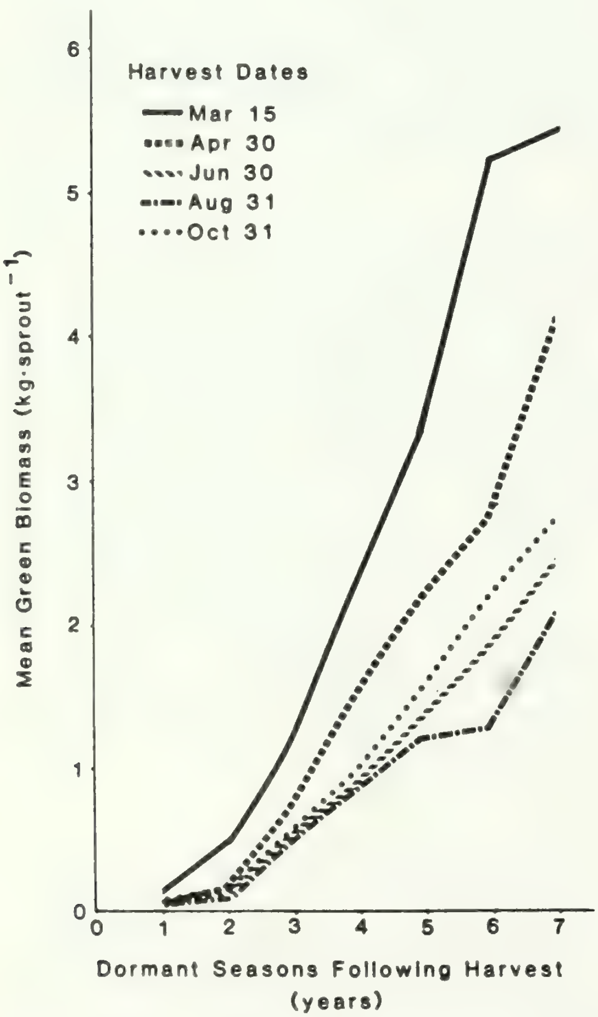


Figure 6.--Green biomass productivity per stump of surviving sycamore coppice sprouts for 7 years following five seasonal harvest treatments.

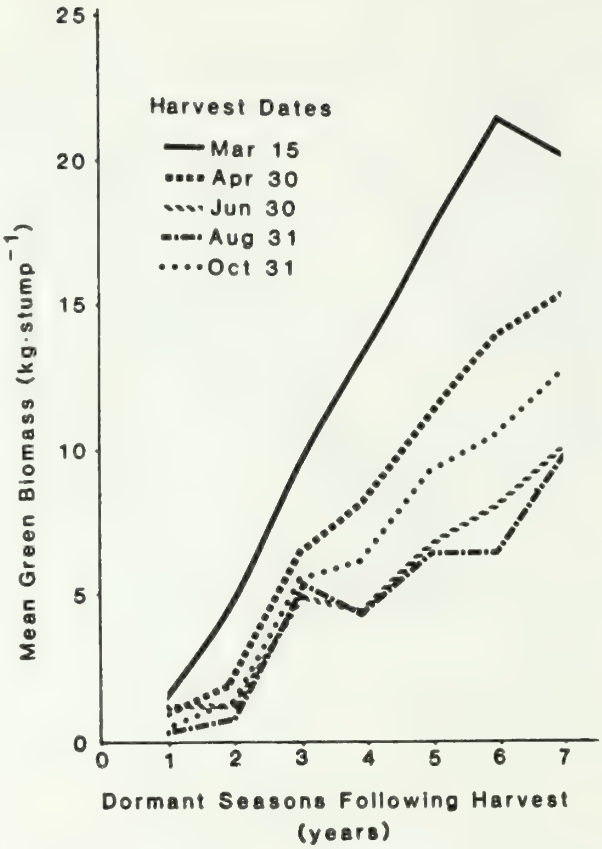


Figure 7.--Mean green biomass productivity per stump of surviving sycamore coppice sprouts for 7 years following five seasonal harvest treatments.

which were significant when dominant sprouts were involved. The biomass growth prior to the vine induced mortality is lost productivity. The growth rate decline detected for the March harvest treatment is also evident in dominant sprout height (Figure 2), dominant DBH (Figure 5), sprout biomass per stump (Figure 7) and total sprout biomass per hectare (Figure 8) due to dominant sprout mortality.

The mortality of dominant coppice sprouts through breakage or death, has a severe impact on the biomass productivity of a stump system as illustrated by the biomass decline of the March harvest treatment during the 7th growing season and the June and August harvest treatments at the 4th growing season (Figure 7). The effects of sprout mortality on a particular stump may be buffered on an area basis by the increased growing space available to the surrounding coppice stand (Figure 8). Loss of sprouts may be symptomatic of a stump in poor health whose loss will cause a cumulative decline in total area biomass productivity.

The total coppice biomass produced from the March harvest treatment, although significantly superior to the other season-of-harvest treatments, amounts to less than 1.2 Mg $ha^{-1}yr^{-1}$ of ovendry biomass over 7-years due to the poor quality of

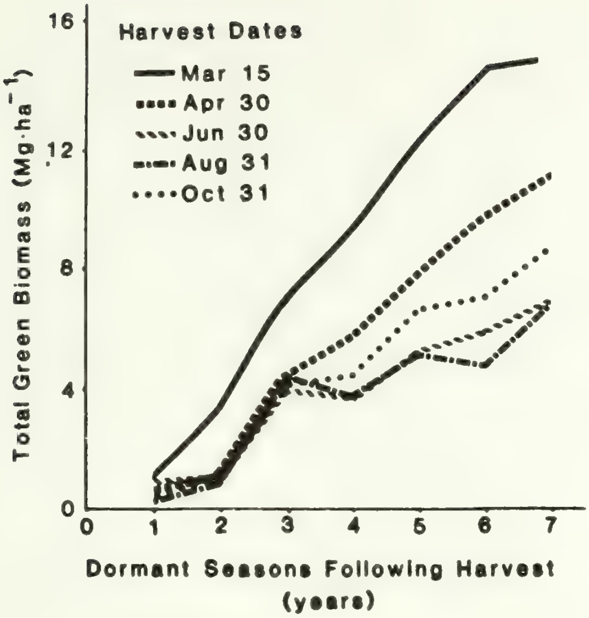


Figure 8.—Mean green biomass productivity per hectare of surviving sycamore coppice sprouts for 7 years following five seasonal harvest treatments.

this site for sycamore. The original seedling stand produced 2.52 Mg ha$^{-1}$yr$^{-1}$ of ovendry biomass over 12-years prior to coppicing. On a good site for sycamore located in the county south of this study, Torreano (1986) reports biomass yields ranging from 4.74 Mg ha$^{-1}$yr$^{-1}$ for 6-year-old seedlings to 2.14 Mg ha$^{-1}$yr$^{-1}$ for a combined 6 year growth cycle consisting of 4-year-old seedling yields and 2-year-old coppice yields.

## CONCLUSIONS

The superior productivity of sycamore stump coppice from late dormant-season-harvested trees (March treatment) is evident in sprout height, DBH and biomass growth. The uniformity of the rate of height growth of dominant coppice sprouts for all seasonal harvesting treatments is a partial reflection of the site index while sprout height at a point in time is more a function of the actual growing months experienced.

The superior rate of dominant sprout diameter growth from the late dormant-season-harvested trees has the greatest impact on the rate of total biomass productivity. Coppice from the March harvest treatment may utilize the full contigent of stored nutrients in the root system, and the full initial growing season for sprout growth, to gain a growth advantage over later harvest treatment coppice. The earlier within-stump sprout competition from the March harvest treatment ensures early elimination of some of the subdominant sprouts and allows dominant sprouts to take advantage of the increased growing space.

The number of sprouts per stump is affected by the season-of-harvest until the carrying capacity of the stumps and site is reached. On this site, the carrying capacity for sycamore was reached after the 2nd growing season. Different species and site qualities are expected to shift this equilibrium point.

Weed competition control may be as important in hardwood coppice plantation management as it is recognized to be in hardwood seedling plantations. This may have a significant effect on the assumptions made to economically justify coppice plantation management systems, thereby dictating directions for technology development.

The lowest level of resultant hardwood coppice productivity occurred to those plants cut during the active season when the root systems are at their lowest energy level. Therefore, pine plantation site preparation efforts will be most effective in controlling hardwood competition if performed during the growing season.

## ACKNOWLEDGEMENTS

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# SHORT-ROTATION SEEDLING AND COPPICE BIOMASS YIELDS AND NUTRIENT CONTENT OF SEVEN TREE SPECIES IN NORTH CAROLINA[1/]

S. J. Torreano and D. J. Frederick

Abstract.--Aboveground biomass production and nutrient content for seven-year-old seedlings and two-year-old coppice grown on a Coastal Plain red river bottomland and Piedmont upland are presented. Spacings of 0.8x1.5, 1.5x1.5, and 2.5x1.5 m were used. On the bottomland, sweetgum (Liquidambar styraciflua L.) produced the greatest seven-year seedling biomass yields (52.7 Mg ha; 0.8x1.5 m spacing, followed by sycamore (Platanus occidentalis L.), and European black alder (Alnus glutinosa L. Gaertn.). Loblolly pine (Pinus taeda L.) produced greater seedling yields than hardwoods on the upland site and all except sweetgum on the bottomland. Seedling and coppice yields were generally greater at narrower spacings on both sites. Higher nutrient concentrations in young seedlings and coppice suggest that longer rotations will be needed to increase nutrient utilization efficiency.

## INTRODUCTION

Greater use of hardwoods for pulp, composite wood products, and energy has created a need to grow wood fiber more productively. One silvicultural regime being considered is short-rotation intensive culture (SRIC). SRIC can increase hardwood biomass yields over those of unmanaged, natural stands (Belanger and Saucier 1975). However, hardwoods have specific site requirements and proper matching of species to site is necessary for maximum yields (Kellison and others 1979). An additional factor in the successful application of SRIC is the coppicing ability of hardwoods. Little information exists as to whether indigenous species will coppice adequately to maintain high productivity levels under SRIC regimes. Information on management practices which maximize the survival and productivity of coppice is needed for planning multiple rotations from seedlings.

SRIC with intensive harvesting places higher demands per unit time on site nutrient pools compared to conventional management (Hansen and Baker 1979). Documentation of nutrient removal from harvesting of SRIC stands is needed so that comparisons of nutrient utilization efficiency can be made among species and sites.

Objectives of this study were to compare biomass yields and nutrient content of seedlings and coppice grown under SRIC on a Coastal Plain red river bottomland and Piedmont upland in North Carolina.

## MATERIALS AND METHODS

### Sample Stands

Two plantations were established in May, 1979. The first is located on a floodplain of the Roanoke River in Bertie County, North Carolina. The soil on this Atlantic Coastal Plain red river bottomland is a Congaree fine, sandy loam (Cawthorn 1970). Site preparation began after the original bottomland hardwood stand was harvested, and consisted of shearing residuals, windrowing and burning, followed by double-discing. After discing, the site was treated with glyphosate. Seedlings (1-0) of seven species: European black alder (Alnus glutinosa L. Gaertn); sweetgum (Liquidambar styraciflua L.): loblolly pine (Pinus taeda L.); eastern cottonwood (Populus deltoides Bartr. ex Marsh); sycamore (Platanus occidentalis L.); water-willow oak (Quercus spp.); and green ash (Fraxinus pennsylvanica Marsh) - were hand planted at 0.8 x 1.5 m, 1.5 x 1.5 m, and 2.5 x 1.5 m spacings.

Experimental design of the plantation was a split-block with five blocks, seven species per block, and three spacing plots per species plot. Species-spacing plots were further divided into four, 25-tree measurement replications (five rows with five tree per row). Measurement replications were bordered 3.1 m on all sides with trees planted at similar spacings. After the first growing season, the soil was regularly cultivated until crown closure to control competition.

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The second plantation was established on an eroded Piedmont upland in Granville County, North Carolina. Soils on this site are a White Store clay loam with slopes of 0-5% (Cawthorn 1970). Site preparation began after the original mixed hardwood pine forest was harvested and was similar to that for the bottomland site. Seedlings of four species: European black alder, sweetgum, loblolly pine and black locust (Robinia pseudoacacia L), were hand planted at 0.5 x 1.5 m, 1.5 x 1.5 m and 2.5 x 1.5 m. Experimental design of the trial was the same as the bottomland except that four blocks, and four species were used.

## Field Measurements

All sampling was done during the dormant season (December - January). Nondestructive sampling of 25-tree replicates began following the second growing season (1981). Destructive sampling was scheduled at age four and six years, with nondestructive sampling in intervening years. During nondestructive sampling years, two out of the possible 10 rows of measurement trees (from each replication) were randomly chosen from each species plot in each block. Survival, height (nearest 0.03 m) and diameter (dbh) to the nearest 0.3 cm were measured. Aboveground woody biomass was estimated by sampling eight trees per species from all spacings over the range of tree sizes. Trees were chosen by a stratified random sample based on diameter. Sample trees were selected from border rows at least 3.1 m from any edge; thus, measurement replications remained intact and border effects were minimized. Sample trees were cut at approximately 5.0 cm aboveground with a chainsaw and weighed to the nearest 0.05 kg to obtain green weight. Trees were sectioned into stem and branch (foliage was also separated and weighed for loblolly pine) components and weighed. Cross-sectional disks approximately 5.0 cm thick were cut from eight sample trees per species at 1/4 and 1/2 total height. Four disks were taken from a composite of medium diameter branches for each tree. A composite random sample of foliage from the loblolly pine crowns was also taken. Disks and foliage from the loblolly pine crowns was also taken. Disks and foliage were sealed in polyethylene bags and stored at 4° C until processing for moisture and nutrient content. Green weights of harvested sample trees were used to develop regression equations. Individual species equations were developed each year by plantation. The form of the equation was:

$$Y = a + b\ (ht * dbh^2) + e$$

where:

Y = whole tree (aboveground green biomass in kg

a b = regression coefficients

ht = total tree height in m

dbh = diameter outside bark at breast height (1.4 m) in cm.

During destructive sampling years, one of four measurement replications was harvested from each spacing plot across all species and blocks, and weighed. Biomass yields from each block were averaged by species and spacing.

Coppice growth and biomass yields were measured after completion of the second growing season. Survival, total height of the dominant sprout per stool (nearest 0.03 m) and total number of coppice sprouts per stool were measured. Coppice biomass yields were obtained by harvesting sprouts in previously cut measurement replications. To estimate dry weight yields, one 1/2 height stem disk and 4 mid length brand disks were cut from eight coppice sprouts over a range of sizes.

Nutrient content of seedling and coppice biomass were determined using a subsampling procedure outlined by Messina and others (1983) for estimating nutrient content of southern hardwoods. Eight trees per species were chosen using the sampling method described previously. Sample trees were selected from measurement replications of medium spacing (1.5 x 1.5 m) for each species from one randomly selected block. Combined stemwood and stembark nutrient concentrations for each seedling were determined from a single disk taken at 1/4 total height. A disk at 1/2 dominant sprout height was used for coppice. Branch nutrient concentrations were determined from a composite sample of four disks from medium diameter branches. Loblolly pine foliage nutrient concentrations were determined from a composite needle sample (four needle fascicles) taken from the upper, middle and lower third of each sample tree.

## Laboratory Determinations

After tissue sample green weights were determined, samples were oven dried at 70° C to a constant weight. Dry weight biomass was then estimated by multiplying the biomass of a component by the appropriate green-to-dry-weight ratio.

Disk and foliar samples were ground to pass a 0.84 mm screen. Samples for nutrient analyses were wet-ashed following procedures described by Parkinson and Allen (1979). Total nitrogen (N) and phosphorus (P) were measured colorimetrically as ammonium salicylate and phosphomolybdenum complexes, respectively on an autoanalyzer. Potassium (K), calcium (Ca), and magnesium (Mg) were deterimined by atomic absorption spectrophotometry. Tissue samples were analyzed in the soils laboratory of the Department of Forestry, North Carolina State University.

Data were analyzed using a split-block analysis of variance (Steel and Torrie 1980). Scheffe's multiple comparison test was used to identify significant differences among treatment means. All tests used a significance level of $p = 0.05$. Statistical analyses were performed using the General Linear Models and Means Procedures of the Statistical Analysis System (SAS 1985).

## RESULTS AND DISCUSSION

Seven-year biomass yields varied between sites and among species and spacing. Due to high mortality, the measurement of black locust was discontinued in 1983. Despite promising early growth on the upland site, seven-year biomass yields of European black alder and sweetgum were significantly lower at all spacings compared with yields of loblolly pine (Table 1).

Table 1. Total aboveground ovendry biomass, wood and bark for seven-year-old seedlings grown on a Piedmont upland in Granville Co., NC.

| Species | Spacing (m) 0.8 x 1.5 | 1.5 x 1.5 | 2.5 x 1.5 |
|---|---|---|---|
| | (Mg/ha$^{-1}$) | | |
| Loblolly pine[1/] | 50.9 a*[2/] | 25.8 a+ | 21.5 a+ |
| Sweetgum | 5.8 b* | 3.7 b* | 1.9 b* |
| European black alder | 5.6 b* | 2.8 b* | 2.5 b* |

[1/]Yields for loblolly pine include foliage.

[2/]Within-column yields followed by the same letter are not significantly different, and within-row yields followed by the same symbol are not significantly different (p=0.05)

The bottomland site showed higher yields compared to the upland with sycamore, sweetgum, European black alder and loblolly pine being superior to green ash, cottonwood and water-willow oak, except for the green ash at the 2.5 x 1.5 m spacing (Table 2).

The poor performance of cottonwood on this site was surprising considering its growth in adjacent natural stands. The U. S. Department of Energy has identified cottonwood, sweetgum and sycamore as the most promising SRIC species for the Southern United States (Ranney and others 1986).

Loblolly pine biomass yields were also greater than those of European black alder at the 1.5 x 1.5 m and 2.5 x 1.5 m spacings. Although loblolly pine yields were comparable to hardwoods on the bottomland, its survival was only 44, 48 and 56% for the narrow, medium and wide spacings, respectively. Siltation caused pockets of mortality in several pine blocks on the bottomland. Loblolly pine can survive flooded conditions if the water is clear and moving. However, clay particles suspended in floodwater can block the stomata in pine needles. Kellison and others (1979) have shown that biomass yields of loblolly pine will surpass yields from southern hardwood species by age 10, on all sites except bottomlands subject to prolonged flooding or stagnant water.

Table 2. Total aboveground ovendry biomass, wood and bark for seven-year-old seedlings grown on a Coastal Plain red river bottomland in Bertie Co., NC.

| Species | Spacing (m) 0.8 x 1.5 | 1.5 x 1.5 | 2.5 x 1.5 |
|---|---|---|---|
| | (Mg/ha$^{-1}$) | | |
| Sweetgum | 52.7 a*[2/] | 25.2 b+ | 21.6 a |
| Sycamore | 46.2 ab* | 35.6 a+ | 25.7 a+ |
| European black alder | 42.3 b* | 24.9 b+ | 12.7 b+ |
| Loblolly pine [1/] | 37.4 b* | 31.7 a+ | 22.7 a+ |
| Cottonwood | 25.6 c* | 23.6 b* | 4.9 b+ |
| Water-willow oak | 15.5 d* | 13.0 c* | 5.8 b+ |

[1/]Yields for loblolly pine include foliage.

[2/]Within-column yields followed by the same letter are not significantly different, and within-row yields followed by the same symbols are not significantly different (p = 0.05).

Differences in biomass productivity between the bottomland and upland sites were highly significant. Seven-year sweetgum yields on the bottomland were nine times greater than sweetgum yields on the upland at similar spacings (Table 3). Sweetgum is the most site adaptable southern hardwood, but expresses best growth on alluvial soils on bottomlands (Kellison and others 1979).

Averaged over spacings, foliage comprised approximately 10 and 12 % of total dry biomass of loblolly pine stands on the bottomland and upland sites, respectively. Hence, differences in biomass production between loblolly pine and hardwood species producing greater biomass than pine would be even greater if only wood and bark are considered.

European black alder yields were seven times greater on the bottomland compared with yields on the upland (Table 3). Comparatively poor biomass yields for European black alder and sweetgum likely resulted from their sensitivity to low moisture conditions on the upland site. Saucier (1977) reported that growth and survival of European black alder were significantly greater on bottomland sites compared with yields on Piedmont uplands in Georgia. A further detriment to growth of European black alder is its precocious flowering habit. After the third growing season, flowering had developed at the expense of

Table 3. Comparison of seven-year seedling biomass, wood and bark on a Piedmont upland and Coastal Plain red river bottomland in Bertie Co., NC (0.8 x 1.5 m spacing).

| | UPLAND | BOTTOMLAND |
|---|---|---|
| | --------($Mg/ha^{-1}$)-------- | |
| Loblolly pine [1/] | 50.9 a[2/] | 37.4 c |
| Sweetgum | 5.8 b | 52.7 a |
| European black alder | 5.6 b | 42.3 b |

[1/]Yields for loblolly pine also include foliage.

[2/]Within-column yields followed by the same letter are not significantly different ($p = 0.05$).

vegetative growth on the upland while flowering was less abundant on the bottomland.

### Effects of Spacing on Seedling Biomass

The effect of spacing on biomass yields for both sites varied. On the upland site, only loblolly pine yields differed significantly among spacings (Table 1). After seven growing seasons, biomass accumulations tended to be highest at narrow (0.8 x 1.5 m) spacings. Biomass yields were significantly greater at the narrower spacings for all species on the bottomland except cottonwood and oak (Table 2). The inverse relationship between seedling biomass yields and spacing under SRIC has been well documented (Steinbeck and May 1971; Wittwer and others 1978).

Determination of an optional spacing for SRIC plantations depends on rotation ages, species and site quality. An optimal spacing allows for rapid site occupancy and limits mortality from between-tree competition. Analysis of spacing effects on seedling mortality indicated that there were no differences in mortality among species and spacings on either site. Although the spacings in this study are limited in range, Belanger and Pepper (1978) found no relationship between stocking (ranging from 200 to 27000 trees $ha^{-1}$), and mortality for six-year-old sycamore seedlings.

After seven growing seasons, greatest mean annual biomass increment (MAI) was 7.5 $Mg/ha^{-1}/yr^{-1}$ for sweetgum at 0.8 x 1.5 m spacings on the bottomland. Maximum MAI's from this study were low to intermediate compared with the 4.0 to 9.0 mg/ha/yr given by Hansen and Baker (1979) as the mean annual biomass production from SRIC plantations in the United States. Some of the greater yields found in the literature were found in stands which had been heavily fertilized and irrigated. Productivity of the best growing hardwoods on the bottomland was high compared with biomass productivity of natural southern hardwood forests. Messina and others (1986) report an average total aboveground biomass accumulation rate (including foliage) for Southern Coastal Plain bottomland hardwood stands of 4.3 $Mg/ha^{-1}/yr^{-1}$ at 10 years.

### Coppice Biomass Yields

Two-year biomass (wood and bark) yields were greatest for cottonwood on the bottomland (2.91 $Mg/ha^{-1}$ at a 1.5 x 1.5 m spacing), and for European black alder on the upland (2.91 $Mg/ha^{-1}$; 0.8 x 1.5 m spacing) (Table 4).

The similarity in coppice biomass production between sites was unexpected considering the significant differences found for hardwood seedling. An important attribute of coppice is the potential for biomass yields to exceed same age seedling yields by 20 - 100% (Ranney and others 1985). Results from our study support those findings. Biomass of two-year-old seedlings for most species and spacings on both sites. However, on the bottomland, two-year coppice yields for green ash were less than yields for green ash seedlings at 0.8 x 1.5 and 1.5 x 1.5 m spacings because of deer browsing. Coppice yields were at least 80% greater than seedling yields for all other species and spacings on both sites after two growing seasons. Biomass yields were higher at the narrow spacings on both sites, except for cottonwood, European black alder and sycamore on the bottomland (Table 4).

Following seedling harvests, survival was at least 85% for most species on both sites. Death of coppice stools was a problem for European black alder and cottonwood on the bottomland. Survival of cottonwood stools was only 34% averaged over spacings. European black alder had the poorest survival with only 27% averaged over spacings of coppice stools living after the second growing season. Survival of European black alder coppice stools was poorer on the bottomland (27%), compared with the upland (84%), averaged over spacings. Survival of sweetgum stools was also lower on the bottomland (62%), compared with the upland (88%). Prolonged annual spring floods on the bottomland during the first and second year of coppice growth may have resulted in greater stool mortality.

No significant differences in stool mortality among spacings were found for any species on either site. However, survival tended to be lower at narrower spacings for most species on both sites. Heilman and others (1972) found significantly greater mortality of Populus trichocarpa (Torr. and Gray) with narrower spacings after two growing seasons.

## NUTRIENT ACCUMULATIONS

Spacing had a large influence on nutrient accumulation due to its direct influence on biomass production. Highest nutrient accumulations tended to be at the narrow spacing for both cop-

Table 4. Above ground biomass, wood and bark yields of seedlings and coppice grown on a bottomland and upland site.

| Species | Spacing (m) | BOTTOMLAND 2-yr seedling | BOTTOMLAND 2-yr coppice | UPLAND 2-yr seedling | UPLAND 2-yr coppice |
|---|---|---|---|---|---|
| | | (mg/ha$^{-1}$) | | | |
| European black alder | 0.8 x 1.5 | 0.50 | 0.89 | 0.84 | 2.91 |
| | 1.5 x 1.5 | 0.20 | 1.08 | 0.49 | 1.12 |
| | 2.5 x 1.5 | 0.09 | 0.88 | 0.38 | 0.89 |
| Sweetgum | 0.8 x 1.5 | 0.09 | 1.79 | 0.14 | 1.58 |
| | 1.5 x 1.5 | 0.04 | 1.11 | 0.07 | 1.31 |
| | 2.5 x 1.5 | 0.03 | 1.07 | 0.06 | 0.39 |
| Green ash | 0.8 x 1.5 | 0.50 | 0.23 | - | - |
| | 1.5 x 1.5 | 0.25 | 0.20 | - | - |
| | 2.5 x 1.5 | 0.13 | 0.18 | - | - |
| Cottonwood | 0.8 x 1.5 | 0.50 | 1.59 | - | - |
| | 1.5 x 1.5 | 0.39 | 2.91 | - | - |
| | 2.5 x 1.5 | 0.33 | 1.97 | - | - |
| Oak | 0.8 x 1.5 | 0.21 | 1.09 | - | - |
| | 1.5 x 1.5 | 0.11 | 0.69 | - | - |
| | 2.5 x 1.5 | 0.06 | 0.39 | - | - |
| Sycamore | 0.8 x 1.5 | 0.55 | 0.19 | - | - |
| | 1.5 x 1.5 | 0.29 | 1.37 | - | - |
| | 2.5 x 1.5 | 0.34 | 1.34 | - | - |

pice and seedlings on both sites (Tables 5 and 6). Generally, species producing the most biomass had the highest total nutrient accumulations regardless of nutrient concentrations.

Nutrient concentrations varied with age (Tables 7 and 8). For example, sweetgum coppice on the bottomland site had the following nutrient concentrations (percent of dry weight wood and bark) at two years: N- 0.52; P- 0.07; k- 0.28; Ca- 0.43 and Mg- 0.15. Seedling nutrient concentrations at age seven had decreased to: N- 0.37; P- 0.05; K- 0.19; Ca 0.30 and Mg 0.09. Similar trends of decreasing nutrient concentrations in seedling and coppice biomass with age were observed for most species on both sites. The shift towards lower nutrient rich branches and bark decreases with increasing age of the tree. Generally, nutrient concentrations within a component decrease with age. The exception is for Ca in bark (Messina and others 1986).

Lower nutrient concentrations and increasing mean annual biomass accumulation lead to greater efficiency of nutrient use (utilization efficiency = kg of dry biomass/kg of nutrient) with age (Tables 9 and 10).

On both the upland and bottomland, nutrient utilization efficiency of seven-year-old seedlings was greater than that of two-year-old coppice. The exception was European black alder coppice on the Bottomland which had a higher utilization efficiency for P and Mg. Sycamore seedlings generally had the highest utilization efficiency of all species on the bottomland, except in the case of loblolly pine and Ca. This higher efficiency resulted from high biomass accumulation and relatively low Ca concentrations for loblolly pine on both sites. Relatively lower utilization efficiencies for loblolly pine on the upland were due to higher nutrient concentrations compared with hardwood seedlings.

## SUMMARY

Biomass yields of coppice and seedlings varied significantly among species, spacing and between sites in this study. After seven years, narrow spacings continued to produce greater biomass yields for most species. Mortality among spacings was not significantly different for any species on either site. Spacing-induced competition was not a detectable problem at these ages. Therefore, other factors such as increased planting costs, harvesting equipment limitations and anticipated end use may be more important when evaluating SRIC regimes on similar sites.

Table 5. Nutrient content of 7-year-old seedling and 2-year-old coppice biomass grown on a red river bottomland -- Bertie Co., NC.

| | | Nutrient Contents | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Seedling | | | | | Coppice | | | | |
| Species | Spacing (m) | N | P | K | Ca | Mg | N | P | K | Ca | Mg |
| | | Kg/ha$^{-1}$ | | | | | | | | | |
| Green ash | 0.8x1.5 | 99.6 | 17.6 | 61.5 | 90.8 | 17.6 | 1.3 | 0.2 | 0.8 | 1.0 | 0.3 |
| | 1.5x1.5 | 64.9 | 11.5 | 40.1 | 59.2 | 11.5 | 1.1 | 0.2 | 0.7 | 0.9 | 0.3 |
| | 2.5x1.5 | 57.8 | 10.2 | 35.7 | 52.7 | 10.2 | 1.0 | 0.2 | 0.6 | 0.8 | 0.3 |
| Sycamore | 0.8x1.5 | 120.1 | 23.1 | 87.8 | 87.8 | 23.1 | 1.1 | 0.1 | 0.4 | 0.6 | 0.2 |
| | 1.5x1.5 | 92.5 | 17.8 | 67.6 | 67.6 | 17.8 | 8.0 | 1.0 | 2.7 | 4.4 | 1.1 |
| | 2.5x1.5 | 66.8 | 12.9 | 48.8 | 48.8 | 12.9 | 7.7 | 0.9 | 2.7 | 4.3 | 1.1 |
| Water-willow oak | 0.8x1.5 | 60.5 | 9.3 | 35.6 | 49.6 | 10.9 | 4.5 | 0.7 | 3.4 | 5.0 | 0.7 |
| | 1.5x1.5 | 50.7 | 7.8 | 29.9 | 41.6 | 9.1 | 2.9 | 0.4 | 2.1 | 3.2 | 0.4 |
| | 2.5x1.5 | 22.6 | 3.5 | 13.3 | 18.6 | 4.1 | 1.6 | 0.3 | 1.2 | 1.8 | 0.3 |
| Sweetgum | 0.8x1.5 | 195.0 | 26.4 | 100.1 | 158.1 | 47.4 | 9.4 | 1.2 | 5.1 | 7.7 | 2.7 |
| | 1.5x1.5 | 93.2 | 12.6 | 47.9 | 75.6 | 22.7 | 5.8 | 0.7 | 3.1 | 4.7 | 1.7 |
| | 2.5x1.5 | 79.9 | 10.8 | 41.0 | 64.8 | 19.4 | 5.8 | 0.7 | 3.1 | 4.7 | 1.7 |
| Cottonwood | 0.8x1.5 | 89.6 | 15.4 | 56.3 | 92.2 | 23.0 | 7.8 | 1.3 | 8.0 | 8.6 | 1.9 |
| | 1.5x1.5 | 82.6 | 14.2 | 51.9 | 85.0 | 21.2 | 14.2 | 2.4 | 14.6 | 15.5 | 3.4 |
| | 2.5x1.5 | 17.2 | 2.9 | 10.8 | 17.6 | 4.4 | 9.8 | 1.6 | 10.1 | 10.7 | 2.3 |
| European black alder | 0.8x1.5 | 181.9 | 25.4 | 88.8 | 139.6 | 25.4 | 5.6 | 0.5 | 2.4 | 3.0 | 0.5 |
| | 1.5x1.5 | 107.1 | 14.9 | 52.3 | 82.2 | 14.9 | 6.9 | 0.6 | 2.9 | 3.6 | 0.6 |
| | 2.5x1.5 | 54.6 | 7.6 | 26.7 | 41.9 | 7.6 | 5.6 | 0.5 | 2.4 | 3.0 | 0.5 |
| Loblolly | 0.8x1.5 | 133.9 | 21.6 | 87.8 | 41.0 | 21.0 | - | - | - | - | - |
| | 1.5x1.5 | 113.5 | 18.3 | 74.4 | 34.7 | 17.8 | - | - | - | - | - |
| | 2.5x1.5 | 81.3 | 13.1 | 53.3 | 24.9 | 12.7 | - | - | - | - | - |

Table 6. Nutrient content of 7-year-old seedling and 2-year-old coppice biomass grown on a Piedmont upland--Granville Co., NC

| | | Nutrient Contents | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Seedling | | | | | Coppice | | | | |
| Species | Spacing (m) | N | P | K | Ca | Mg | N | P | K | Ca | Mg |
| | | Kg/ha$^{-1}$ | | | | | | | | | |
| Sweetgum | 0.8x1.5 | 18.0 | 2.3 | 8.1 | 33.1 | 6.2 | 6.1 | 0.9 | 6.1 | 10.9 | 1.9 |
| | 1.5x1.5 | 11.5 | 1.5 | 5.1 | 21.1 | 4.0 | 5.1 | 0.8 | 5.1 | 9.0 | 1.6 |
| | 2.5x1.5 | 7.8 | 1.0 | 3.5 | 14.3 | 2.7 | 1.5 | 0.2 | 1.5 | 2.7 | 0.5 |
| European black alder | 0.8x1.5 | 21.8 | 2.2 | 9.5 | 14.0 | 3.9 | 20.0 | 1.7 | 9.0 | 10.2 | 2.6 |
| | 1.5x1.5 | 10.9 | 1.1 | 4.8 | 7.0 | 2.0 | 7.7 | 0.7 | 3.5 | 10.1 | 1.0 |
| | 2.5x1.5 | 6.6 | 0.7 | 2.9 | 4.3 | 1.2 | 6.1 | 0.5 | 2.6 | 3.1 | 0.8 |
| Loblolly | 0.8x1.5 | 178.2 | 35.6 | 137.4 | 86.5 | 35.6 | - | - | - | - | - |
| | 1.5x1.5 | 90.3 | 18.1 | 69.4 | 41.3 | 18.1 | - | - | - | - | - |
| | 2.5x1.5 | 75.3 | 15.1 | 36.6 | 34.4 | 15.1 | - | - | - | - | - |

Table 7. Nutrient concentration in percentage dry weight of total tree wood and bark for 7-year-old seedlings and 2-year-old coppice on a Coastal Plain red river bottomland--Bertie Co., NC.

| Species | SEEDLING | | | | | COPPICE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | N | P | K | Ca | Mg |
| | percentage | | | | | | | | | |
| Sweetgum | .37 | .05 | .19 | .30 | .09 | .52 | .07 | .28 | .43 | .15 |
| Oak | .39 | .06 | .23 | .32 | .07 | .41 | .06 | .31 | .45 | .12 |
| Sycamore | .26 | .05 | .19 | .21 | .05 | .58 | .07 | .20 | .32 | .08 |
| Green ash | .34 | .06 | .21 | .31 | .06 | .56 | .11 | .36 | .44 | .13 |
| European black alder | .43 | .06 | .21 | .33 | .06 | .63 | .06 | .27 | .33 | .06 |
| Cottonwood | .35 | .06 | .22 | .36 | .09 | .49 | .08 | .50 | .53 | .12 |
| Loblolly Pine1/ | .36 | .06 | .24 | .11 | .06 | - | - | - | - | - |

1/Data for loblolly pine includes foliage.

Table 8. Nutrient concentration in percentage dry weight of total tree wood and bark for 7-year-old seedlings and 2-year-old coppice on a Piedmont upland site -- Granville Co., NC.

| Species | SEEDLING | | | | | COPPICE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | N | P | K | Ca | Mg |
| | percentage | | | | | | | | | |
| Sweetgum | .31 | .04 | .14 | .57 | .10 | .39 | .06 | .39 | .69 | .12 |
| European black alder | .39 | .04 | .17 | .25 | .07 | .69 | .06 | .31 | .35 | .09 |
| Loblolly Pine1/ | .35 | .05 | .23 | .13 | .06 | - | - | - | - | - |

1/Data for loblolly pine includes foliage.

Biomass yields of loblolly pine were significantly greater than hardwood seedling yields at all spacings on the upland site. Expensive inputs (i.e. fertilization, site preparation and competition control, etc.) required for SRIC management of hardwoods on sites such as this upland can not be recommended. However, SRIC was a relatively productive management regime on the bottomland especially when compared to natural southern hardwood stands growing on similar sites. Sweetgum and sycamore are the best species for this and similar sites. Biomass yields of two-year-old coppice were greater than that of same age seedlings and suggests that coppicing will likely be a successful mode of regeneration.

Nutrient utilization efficiency increased with age and suggests that longer rotations for both coppice and seedlings are best. Increasing nutrient utilization efficiency occurs as nutrient concentrations of biomass decrease and mean annual biomass production increases with age.

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Table 9. Nutrient utilization efficiencies for 7-year-old seedlings and 2-year-old coppice grown under short-rotation intensive culture on a Coastal Plain red river bottomland -- Bertie Co., NC.

| | | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|
| | | --kg biomass/kg nutrient-- | | | | |
| Green ash | Seedling | 294 | 1665 | 477 | 323 | 1665 |
| | Coppice | 176 | 1145 | 286 | 229 | 763 |
| Sycamore | Seedling | 385 | 2000 | 526 | 526 | 2000 |
| | Coppice | 173 | 1483 | 494 | 310 | 1214 |
| Water-willow | Seedling | 256 | 1667 | 435 | 313 | 1442 |
| | Coppice | 241 | 1551 | 319 | 217 | 1551 |
| Sweetgum | Seedling | 270 | 1996 | 526 | 333 | 1112 |
| | Coppice | 190 | 1488 | 350 | 232 | 661 |
| Cottonwood | Seedling | 286 | 1662 | 455 | 278 | 1113 |
| | Coppice | 203 | 1221 | 198 | 185 | 835 |
| European black alder | Seedling | 233 | 1659 | 477 | 303 | 1665 |
| | Coppice | 160 | 1788 | 373 | 298 | 1788 |
| Loblolly Pine | Seedling | 279 | 1731 | 426 | 912 | 1781 |

Table 10. Nutrient utilization efficiencies for 7-year-old seedlings and 2-year-old coppice grown under short-rotation intensive culture on a Piedmont upland -- Granville Co., NC.

| | | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|
| | | --kg biomass/kg nutrient-- | | | | |
| Sweetgum | Seedling | 322 | 2522 | 716 | 175 | 935 |
| | Coppice | 258 | 1750 | 258 | 144 | 829 |
| European black alder | Seedling | 257 | 2545 | 589 | 400 | 1436 |
| | Coppice | 146 | 1712 | 323 | 285 | 1119 |
| Loblolly Pine | Seedling | 286 | 1430 | 370 | 588 | 1430 |

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# Pine-Hardwood Regeneration

Moderator:

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SILVICULTURAL IMPLICATIONS OF MIXED PINE-HARDWOOD

STANDS IN THE PIEDMONT[1]

Herbert A. Knight and Douglas R. Phillips[2]

Abstract.--In the Southeast Piedmont, almost 5.8 million acres, or 21 percent, of the forests are mixed stands containing 25 to 75 percent hardwood and 25 to 75 percent pine. Analysis of forest survey plot data indicates that yield in these stands varies with the proportion of pine present.

Keywords: Timberland, Southeast Piedmont, mixed pine-hardwood stands.

## INTRODUCTION

Many of the timber stands on the Piedmont Plateau of the Southeastern United States are mixtures of pines and hardwoods. This paper quantifies and describes the full range of mixed pine-hardwood stands and examines their yields.

Sandwiched between the Southern Appalachian Mountains and the South Atlantic Coastal Plain, the Southeast Piedmont extends from northern Virginia to west-central Georgia (fig. 1). Delineations of this region vary among different geographical classifications. As defined here, the region comprises 6 of the 21 forest survey units the USDA Forest Service inventories in the Southeast (Larson and others 1961). This delineation includes most of the area that Austin (1965) designated as the Southern Piedmont.

The Southeast Piedmont contains almost 44 million acres of land, most of which is best characterized as gently rolling upland. Generally, the elevation ranges from about 500 to 1,000 feet, and increases gradually from east to west. Exceptions are the mountains in upstate South Carolina and some higher foothills along the eastern side of the Southern Appalachians. Numerous "red water" rivers and streams carrying heavy silt loads flow through the region (Stubbs 1966). The floodplains of these streams are best characterized as bottom land. The ratio of upland to bottom land is about 7 to 1.

Figure 1.--The Southeast Piedmont.

## THE TIMBER RESOURCE

Since settlement, most of the upland and much of the bottom land has been in and out of timber production one or more times (Boyce and Knight 1979 and 1980). Currently, forests occupy 62 percent of the land in the region. Almost 27 million acres, or 99 percent of these forests, are classed as timberland. The small remainder is withdrawn from timber utilization through statute or administrative designation and reserved for other uses. Hardwoods clearly dominate bottom land forests and in the absence of fire and man's intervention, hardwoods tend to dominate pines on upland forests. About half of the timberland held by small nonindustrial private

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landowners supports hardwood stands (Bechtold and Phillips 1983). Even on timberland owned or leased by forest industry, pines dominate the stocking on less than 60 percent of the land. When all owners are grouped, pine stocking exceeds the stocking of hardwood on less than 40 percent of the existing timberland in the Southeast Piedmont.

The pine-hardwood mix varies greatly by stand age (table 1). Pine exceeds hardwood stocking in more than half of the stands 11 to 40 years old. The larger amount of pine in stands of these ages reflects extensive reversion of cropland and pastureland to pine forest between 1940 and 1970. In 1940, more than 20 million acres in the Southeast Piedmont were classed as either cropland or pastureland. By 1970, fewer than 12 million acres were used for these purposes. The natural and artificial establishment of pine trees on most of the acres taken out of agricultural use resulted in a net increase in area of timberland from 22 to 28 million acres over this same 30-year period. Urban expansion, new roads, highways, and reservoirs accounted for most of the remaining diverion from agricultural use.

From 1940-1970, the widespread establishment of pine on former agricultural land tended to compensate for hardwood encroachment following the harvesting of pine. Pine volume as a percent of total volume stabilized at about 42 percent (fig. 2). In the absence of extensive reversion of agricultural land to pine timber since 1970, the pine component of the resource has dropped to below 40 percent.

Table 1.--Area of timberland in the Southeast Piedmont, by stand-age class, by pine stocking percent

| Stand-age class (years) | All stands | Pine stocking percent[a] Less than 25 | 25-49 | 50-74 | 75+ |
|---|---|---|---|---|---|
| | - - - - - | Thousand acres | - - - - - | | |
| 00-10 | 4,424 | 1,673 | 703 | 370 | 1,678 |
| 11-20 | 3,751 | 1,322 | 474 | 386 | 1,569 |
| 21-30 | 3,921 | 1,188 | 384 | 447 | 1,902 |
| 31-40 | 4,631 | 1,927 | 577 | 452 | 1,675 |
| 41-50 | 3,879 | 2,196 | 462 | 466 | 755 |
| 51+ | 6,369 | 4,812 | 632 | 401 | 524 |
| Total | 26,975 | 13,118 | 3,232 | 2,522 | 8,103 |

[a]Pine stocking as a percent of all live tree stocking in the stand.

Other than fire protection, most investments in forestry and improved silvicultural practices in the Southeast Piedmont over the past 50 years have been made to favor pines. Most silvicultural investments have been in such practices as site preparation, artificial regeneration, and various kinds of hardwood control. Still, these practices have not reversed the strong successional trend toward hardwood in the region. Except on old-field sites, it is difficult to establish and maintain pure stands of pine in the Southeast Piedmont. Even in existing stands with evidence of artificial regeneration, there are significant amounts of hardwood. Pines account for 75 percent or more of the stocking in fewer than 80 percent of the plantations. Pines account for 75 percent or more of the stocking in fewer than 70

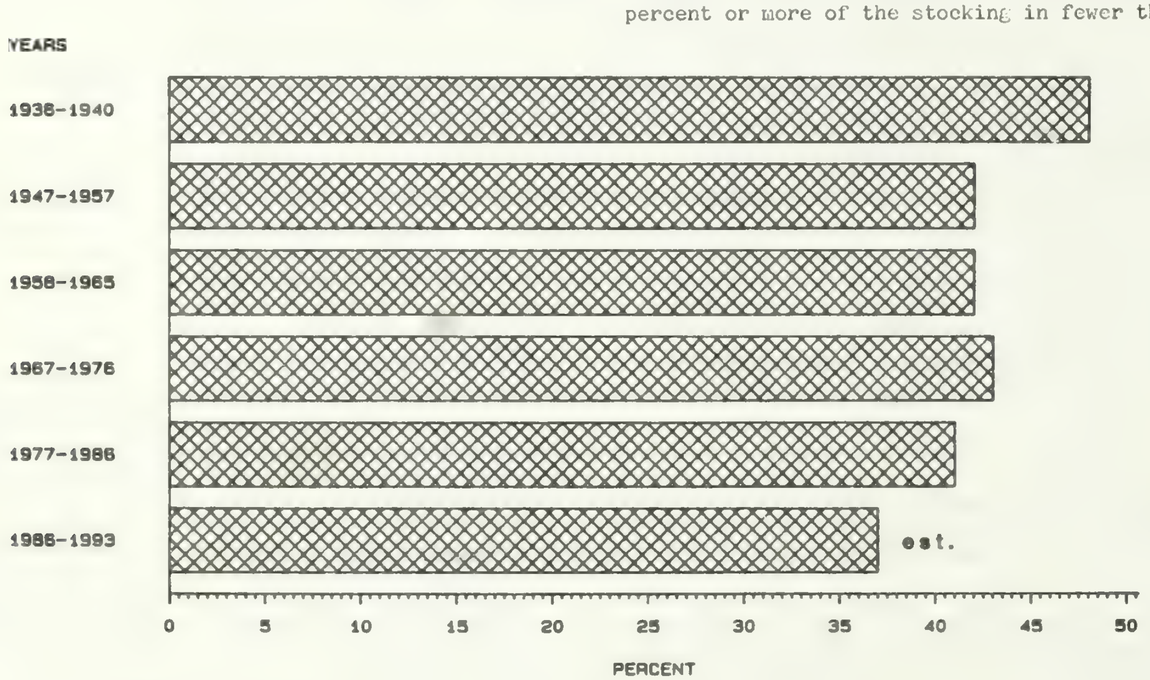


Figure 2.--Pine volume as a percent of total volume in the Southeast Piedmont.

percent of the plantations less than 10 years old (table 2). Perhaps mixed pine-hardwood stands are the most affordable compromise for managed upland stands in which hardwoods have become well established.

Table 2.--Area of timberland in the Southeast Piedmont with evidence of artificial regeneration, by stand-age class, by pine stocking percent

| Stand-age class (years) | All stands | Pine stocking percent[a] | | | |
|---|---|---|---|---|---|
| | | Less than 25 | 25-49 | 50-74 | 75+ |
| | - - - - - - Thousand acres - - - - - - | | | | |
| 00-10 | 1,534 | 80 | 219 | 167 | 1,068 |
| 11-20 | 766 | 8 | 25 | 84 | 649 |
| 21-30 | 643 | 7 | -- | 27 | 609 |
| 31+ | 132 | 4 | -- | 11 | 117 |
| Total | 3,075 | 99 | 244 | 289 | 2,443 |

[a]Pine stocking as a percent of all live stocking in the stand.

## Mixed Pine-Hardwood Stands

The most recent forest surveys show 3.2 million acres, or 12 percent of the region's timberland, as oak-pine forest type. These are forests in which hardwoods constitute a plurality, but in which pines account for 25 to 50 percent of the stocking. Hardwoods account for 25 to 50 percent of the stocking on 2.5 million additional acres classed as pine types. Altogether, more than 5.7 million acres, or 21 percent of the timberland, support timber stands best characterized as mixed pine-hardwood (table 1). This percentage does not vary greatly by stand-age class up through age 50.

The species composition of these mixed stands varies. Loblolly pine (*Pinus taeda* L.), shortleaf pine (*Pinus echinata* Mill.), and Virginia pine (*Pinus virginiana* Mill.) account for almost 95 percent of the total softwood volume. Loblolly alone accounts for 58 percent, followed by shortleaf with 20 percent and Virginia with 16 percent.

Together, a wide variety of oaks (*Quercus* spp.) account for 40 percent of the hardwood volume in these mixed stands. Among these, white oak (*Quercus alba* L.) predominates and accounts for about 11 percent of the total hardwood volume. Other than oaks, the two leading hardwood species in these mixed stands, are sweetgum (*Liquidambar styraciflua* L.) and yellow-poplar (*Liriodendron tulipifera* L.), accounting for 21 and 17 percent, respectively.

## Yield Comparisons

Faced with the reality and persistence of these mixed pine-hardwood stands, timberland managers need some measure of the yields in these mixed stands relative to yields achieved in pure stands. Although the Forest Survey is neither designed nor intended to provide conventional growth and yield data, it does provide measures of stand performance across the broad range of sites, stocking levels, and forest conditions within the region. Average volumes per acre are presented by stand-age class and by pine stocking class in tables 3 and 4. These averages are based on measurements taken on 7,450 sample plots distributed in timberland throughout the Southeast Piedmont. Since these averages do not reflect differences among sites and stocking levels, they differ from published empirical yields developed from Forest Survey data (McClure and Knight 1984).

Table 3.--Average volume of growing stock per acre of timberland in the Southeast Piedmont, by stand-age class, by pine stocking percent

| Stand-age class (years) | All stands | Pine stocking percent[a] | | | |
|---|---|---|---|---|---|
| | | Less than 25 | 25-49 | 50-74 | 75+ |
| | - - - - - - - - Cubic feet - - - - - - - | | | | |
| 00-10 | 180 | 244 | 256 | 149 | 92 |
| 11-20 | 607 | 545 | 580 | 565 | 678 |
| 21-30 | 1,282 | 879 | 976 | 1,250 | 1,603 |
| 31-40 | 1,637 | 1,412 | 1,337 | 1,688 | 1,986 |
| 41-50 | 1,982 | 1,806 | 1,827 | 2,280 | 2,404 |
| 51+ | 2,161 | 2,112 | 2,055 | 2,449 | 2,519 |

[a]Pine stocking as a percent of all live tree stocking in the stand.

Table 3 clearly shows that average volume of growing stock per acre increases as pine stocking percent increases, assuming no significant difference in average site and stocking. This correlation is particularly evident in stands where pines account for 25 percent or more of the existing stocking of all live trees. For example, in the 21- to 30-year age class, average volume per acre in stands where pines account for 75 percent or more of the stocking is 64 percent greater than the average in stands where pines account for 25 to 49 percent of the existing stocking. It is 28 percent greater than the average in stands where pines account for 50 to 74 percent of the existing stocking.

The largest differences in average volume per acre by pine stocking percent are in the 21- to 30-year age class. As stand age increases, the differences diminish. Although not presented, the same correlations hold when average volume per acre is calculated for all live trees 5.0 inches and larger in diameter at breast height (d.b.h.) rather than for growing stock alone. Distribution of the additional volume in rough and rotten hardwood trees does not alter the conclusion that average volume per acre increases as pine stocking percent increases.

Similar averages are presented for the sawtimber portion of growing stock expressed in board feet (table 4). Again, the same correlations as found in cubic volume per acre are evident. One additional factor to keep in mind while interpreting the differences in average board-foot volume per acre is a key difference in merchantability standards between pine and hardwood. For pines, board-foot volume is assigned to growing-stock trees 9.0 inches d.b.h. and larger; for hardwoods, board-foot volume is assigned to growing-stock trees 11.0 inches d.b.h. and larger.

Table 4.--Average volume of sawtimber per acre of timberland in the Southeast Piedmont, by stand-age class, by pine stocking percent

| Stand-age class (years) | All stands | Pine stocking percent[a] | | | |
|---|---|---|---|---|---|
| | | Less than 25 | 25-49 | 50-74 | 75+ |
| | Board feet[b] | | | | |
| 00-10 | 397 | 499 | 690 | 223 | 211 |
| 11-20 | 1,020 | 1,024 | 1,417 | 983 | 905 |
| 21-30 | 2,945 | 1,719 | 2,265 | 2,582 | 3,934 |
| 31-40 | 4,361 | 3,261 | 3,376 | 4,861 | 5,831 |
| 41-50 | 6,127 | 5,074 | 5,503 | 7,641 | 8,641 |
| 51+ | 7,691 | 7,311 | 7,325 | 9,488 | 10,239 |

[a]Pine stocking as a percent of all live tree stocking in the stand.

[b]International 1/4-inch rule.

Other significant measures are differences between the proven yields in planted stands and natural stands. Average volumes per acre were developed for stands with evidence of artificial regeneration, by stand-age class, by pine stocking percent (tables 5 and 6). Most of the samples were in stands 30 years old and younger. In comparing these averages with those in tables 3 and 4, readers should be aware of several factors affecting the differences: (1) The averages for natural stands reflect a significant amount of volume in older residual trees left during the previous harvest. (2) Artificial regeneration would tend to result in higher pine stocking than natural regeneration, except possibly on old fields. (3) Most of the older pine plantations were established with regular planting stock. Genetically improved planting stock available today will boost yields by 10 to 15 percent.

All of these factors would tend to underestimate the real differences in yields between planted and natural stands. For example, the 20-percent higher estimate for planted stands 20 to 30 years old which are 75 percent or better stocked with pine in table 5 compared with the same average in table 3 is probably a conservative difference. As with natural stands, the average volumes per acre increase as pine stocking percent increases for ages 11 through 30.

Table 5.--Average volume of growing stock per acre of timberland in the Southeast Piedmont with evidence of artificial regeneration, by stand-age class, by pine stocking percent

| Stand-age class (years) | All stands | Pine stocking percent[a] | | | |
|---|---|---|---|---|---|
| | | Less than 25 | 25-49 | 50-74 | 75+ |
| | Cubic feet | | | | |
| 00-10 | 28 | 35 | 25 | 35 | 27 |
| 11-20 | 701 | 281 | 382 | 507 | 743 |
| 21-30 | 1,901 | 727 | -- | 1,660 | 1,926 |
| 31+ | 2,535 | 3,041 | -- | 2,716 | 2,502 |

[a]Pine stocking as a percent of all live tree stocking in the stand.

Table 6.--Average volume of sawtimber per acre of timberland in the Southeast Piedmont with evidence of artificial regeneration, by stand-age class, by pine stocking percent

| Stand-age class (years) | All stands | Pine stocking percent[a] | | | |
|---|---|---|---|---|---|
| | | Less than 25 | 25-49 | 50-74 | 75+ |
| | Board feet[b] | | | | |
| 00-10 | 35 | 26 | 79 | 67 | 21 |
| 11-20 | 576 | 349 | 543 | 806 | 551 |
| 21-30 | 4,943 | 738 | -- | 3,285 | 5,067 |
| 31+ | 9,534 | 11,242 | -- | 11,094 | 9,331 |

[a]Pine stocking as a percent of all live tree stocking in the stand.

[b]International 1/4-inch rule.

## SILVICULTURAL IMPLICATIONS

The analysis of existing mixed stands has shown that stand yields increase as the pine component increases and as management moves from natural to artificial regeneration. These trends are broad generalizations across all sites and are not easily dissected for exact interpretation. Differences could be due largely to differences in stand stocking and merchantability limits between pines and hardwoods. However, even with similar levels of stocking and merchantability limits, the pine component would be expected to produce higher solid wood volumes because pines grow faster than most hardwoods and because pines concentrate more of their growth on the main stem. The higher yields of plantations, as compared with natural stands, can be traced to better stocking and to genetically improved seedlings.

In looking to the future, there are two significant trends occurring in the Piedmont that will affect future management strategies. One, the number of pine plantations is increasing and two, the hardwood component in these plantations is increasing. In 1986, successful plantations

account for more than 10 percent of the timberland in the Southeast Piedmont, compared with 7 percent during the previous survey (Phillips 1983). In stands younger than 10 years old, plantations account for 28 percent of total timberland. This is a significant increase over past decades.

Matching the increase in plantation acreage is a corresponding increase in the hardwood component in these stands. Pines account for 75 percent or more of the stocking in about 80 percent of all plantations, but represent a 75 percent plurality in fewer than 70 percent of plantations younger than 10 years old. These young mixed stands are different than their counterparts because of the way they started. In prior years, many plantations were established on old fields where hardwood competition was minimal or nonexistent. The plantations of the last 10 years have been established primarily on sites where hardwoods make up a significant component of the stand. These new stands provide a challenge in that more decisions must be made regarding hardwood control. Because of the wildlife and esthetic benefits of mixed stands, many managers would not eliminate hardwoods even if they were convinced that overall productivity would improve.

If we assume overall productivity does improve with the reduction of hardwoods through release, does the increased pine production justify the cost of release? What are the yields and comparative values of young even-aged mixed pine-hardwood stands? These questions are beyond the scope of this paper, but, as the trends indicate, we must begin to evaluate our mixed stands if we are to make intelligent management decisions about a significant portion of the resource.

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# GROWTH AND DEVELOPMENT OF SHORTLEAF PINE-HARDWOOD MIXED STANDS FOUR YEARS AFTER REGENERATION[1/]

Douglas R. Phillips and James A. Abercrombie, Jr.[2/]

Abstract.--Three four-year-old shortleaf pine-hardwood mixed stands were inventoried in the winter of 1985. The stands had been established on the Sumter National Forest through low intensive site preparation that involved spring chainsaw felling of residuals and summer burning. Results show that 304 to 414 of the 454 planted pines per acre were free-to-grow after 4 years. Average total height of the pines was 7.9, 8.4 and 9.3 feet in the three stands. Corresponding average total heights for hardwoods was 5.8, 4.9, and 4.7 feet. These mixed stands are well stocked with pines and commercially important hardwoods and thus have high timber value potential. They also can provide many nontimber benefits.

## INTRODUCTION

The Piedmont and mountain regions of the Southeastern United States contains 40 million acres of commercial forest land, 4.6 million acres of which is classed as the oak-pine type. In the Piedmont, an additional 2.5 million acres classed as pine contain 25 to 50 percent hardwoods and thus could be considered as mixed stands (Knight and Phillips, 1986). These mixtures developed primarily as the result of selective harvesting of pines and encroachment of hardwoods into pine stands. Between 1944 and 1964, large acreages of cropland were abandoned in the Piedmont to the seeds of pine trees (Krause 1970). These stands developed into almost pure pine stands because the root stocks of sprouting hardwoods were not present. As these stands developed throughout the sixties and seventies, many of the merchantable pines were harvested. Hardwoods waiting in the understory took over and grew along with the small pines that were left behind. The recent trend has definitely been toward more hardwood and less pines in our southern forests (Boyce and Knight 1979, 1980).

As mixed stands are harvested, landowners find that they must spend large sums of money to convert them back to pure pine. Many owners choose not to make this investment, and as a result, the new stands are less than adequately stocked and frequently dominated by noncommercial or damaged trees. Since pure pine regeneration is so costly and pine management fails to provide many nontimber benefits (firewood, habitat for hunting, recreation, and aesthetics), landowners often opt to do nothing in favor of spending $200 or more per acre to get a pure pine stand. Forest survey statistics show that in spite of concerted efforts to increase the acreage of pine plantations, only 10 percent of commercial timberland in the Piedmont and 2 percent[a] in the mountains is in plantation management (Knight and Phillips, 1986).

An alternative to pine plantation management is the culturing of pine-hardwood mixtures. Mixed stands can provide the nontimber benefits landowners desire, and regeneration can be achieved at approximately half the cost of conventional pure pine management. The approach requires careful scheduling of stand treatments, but much of the work can be done by the individual owner. This paper describes the growth and development of mixed stands of shortleaf pine (*Pinus echinata* Mill.) and hardwoods established through low intensity site preparation techniques that involves chainsaw felling of residuals and summer burning.

## METHODS

### Study Sites

Sample plots were established in three stands on the Andrew-Pickens District of the Sumter National Forest in upstate South Carolina. The three stands, hereafter referred to as Sandy Ford, Whetstone, and Pine Mountain, had similar characteristics: each had a southern exposure, an elevation of approximately 1500 feet, and a

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pine-hardwood overstory. Based on available but less than desirable site trees, site index was estimated to be 60 to 70 for shortleaf pine at 50 years. Soil samples were taken at each site to refine site productivity estimates. The soil at Sandy Ford is Saluda series, a loamy, mixed, mesic, shallow Typic Hapludult. Solum depth (A and B horizons) is 16 to 20 inches. The soil at Whetstone is Evard, a loamy, oxidic, mesic Typic Hapludult. Solum depth is 28 to 32 inches. The soil at Pine Mountain is Walhalla, a fine-loamy, oxidic, mesic Typic Hapludult. The Walhalla solum is 40 to 49 inches deep.

In the winter of 1980, each stand was commercially harvested. Sandy Ford yielded 320 cubic feet per acre (CF/ac) of small pine roundwood (5.0 to 12.0 inches d.b.h.) and 340 CF/ac of small hardwood roundwood (6.0 to 14.0 inches d.b.h.). Whetstone yielded 7.8 thousand board feet per acre (MBF/ac) of pine sawtimber, 0.5 MBF/ac of mixed hardwood sawtimber, 310 CF/ac of small pine and 390 CF/ac of mixed hardwood roundwood. Pine Mountain produced 3.0 MBF/ac of pine, 0.2 MBF/ac of mixed hardwoods, 200 CF/ac of small pine roundwood, and 300 CF/ac of small mixed hardwood roundwood. Almost all of the pines on all sites were shortleaf pine. The most numerous overstory hardwoods were red oaks (Quercus spp.), white oaks (Quercus spp.) and hickories (Carya spp.). Following commercial clearcutting, the stands were opened to the public for firewood salvage. The removal of trees for firewood not only assured full utilization, but reduced site preparation costs. In late spring after residual stems were fully leafed out, they were felled with chainsaws. The felled residuals, along with tops and other logging debris from the harvesting operation, provided the needed fuel for a late summer burn (Abercrombie 1984). Dry leaves and branches of felled residuals were needed to carry a hot surface fire over a fuel bed too moist to support combustion. By burning when the soil was moist, some of the organic layer and most of the incorporated root mat was maintained (Danielovich 1986). This limited erosion which over time should help maintain site productivity.

The following winter (1981), approximately 454 genetically improved shortleaf pine seedlings were planted at a spacing of 8 x 12 ft. No other treatments were applied.

Four growing seasons after treatment (the winter of 1985), the three stands were inventoried to determine species composition, density, and growth of pines and hardwoods. Stem basal diameters in inches and total-tree heights in feet were tallied for planted shortleaf pines that remained free to grow (those receiving full sunlight from above) after 4 years. These trees were on six 52.5 x 82 ft plots spaced 16.4 feet apart and arranged in a 2 x 3 matrix with the long axis running east and west along the slope. Hardwood regeneration and naturally seeded shortleaf pines were measured on three 10- x 120-ft strips spaced approximately 90 feet apart and perpendicular to the slope of each stand. Total heights of all live trees > 2.0 feet tall were tallied in feet by species. With sprout clumps of more than one stem, minor suppressed stems in the clump were not counted.

## RESULTS

A total of 643 planted shortleaf pines were measured at three locations. On a per-acre basis, 304 to 414 trees were free to grow after 4 years. Those values translate into planting success rates of 71 to 91 percent. At Sandy Ford, the 304 planted pines/acre that were not overtopped averaged 1.6 inches in diameter outside bark (d.o.b.) at groundline and 7.9 feet tall. Whetstone had 356 free-growing pines/acre with an average goundline d.o.b. of 1.8 inches and an average total height of 8.4 feet. Pine Mountain had 414 free-growing pines/acre with an average groundline d.o.b. of 2.2 inches and an average height of 9.3 feet (Table 1).

The hardwood components at the three study sites differed considerably in numbers and species composition. Sandy Ford was dominated by oaks (1,945 trees/ac), with substantial amounts of blackgum, hickory and sourwood. Whetstone had a large oak component (1,409 trees/ac), a large amount of blackgum, and a variety of other hardwoods. Pine Mountain had very little oak (298 trees/ac) but significant amounts of blackgum, yellow-poplar and noncommercial hardwoods (Table 2). The noncommercial group at Pine Mountain was dominated by sumac (Rhus glabra L.) with 922 trees/ac. Sandy Ford had the most total hardwoods with 4,898 trees/ac while Whetstone had 4,400 trees/ac and Pine Mountain 3,627 trees/ac.

Table 1. Characteristics of 643 four-year-old shortleaf pine crop trees sampled at three locations

| Location | Trees sampled | Trees/ac | Basal diameter Mean | Basal diameter St. dev. | Basal diameter range | Total height Mean | Total height St. dev. | Total height range |
|---|---|---|---|---|---|---|---|---|
| | ------Number------- | | ----------inches----------- | | | -----------feet----------- | | |
| Sandy Ford | 182 | 304 | 1.6 | 0.5 | 0.7-2.8 | 7.9 | 1.8 | 3.5-12.4 |
| Whetstone | 213 | 356 | 1.8 | 0.6 | 0.7-3.4 | 8.4 | 2.0 | 3.3-13.2 |
| Pine Mountain | 248 | 414 | 2.2 | 0.5 | 1.0-3.6 | 9.3 | 2.0 | 4.6-14.1 |

Table 2. Number of sprout clumps per acre, trees per acre, trees per clump and average total tree height of hardwoods by species and location four years after regeneration.

| Species[a] | Clumps/ac | Trees/ac | Trees/clump | Average total tree height[b] |
|---|---|---|---|---|
| | | | | ----feet----- |
| | | SANDY FORD | | |
| Scarlet oak | 461 | 1,134 | 2.5 | 6.6 |
| Southern red oak | 236 | 324 | 1.4 | 6.0 |
| White oak | 150 | 287 | 1.9 | 6.8 |
| Post oak | 100 | 125 | 1.2 | 6.1 |
| Other oaks | 37 | 75 | 2.0 | 5.0 |
| Blackgum | 1,059 | 1,296 | 1.2 | 4.7 |
| Red maple | 100 | 187 | 1.9 | 5.9 |
| Yellow-poplar | 13 | 25 | 1.9 | 9.6 |
| Hickory | 361 | 474 | 1.3 | 5.7 |
| Sourwood | 162 | 573 | 3.5 | 7.2 |
| Other hardwoods | 187 | 398 | 2.2 | 7.1 |
| All hardwoods | 2,866 | 4,898 | 1.7 | 5.8 |
| | | WHETSTONE | | |
| Scarlet oak | 75 | 125 | 1.7 | 5.2 |
| Southern red oak | 374 | 424 | 1.1 | 5.6 |
| White oak | 274 | 498 | 1.8 | 6.6 |
| Post oak | 212 | 212 | 1.0 | 4.1 |
| Other oaks | 100 | 150 | 1.5 | 5.9 |
| Blackgum | 972 | 1,259 | 1.3 | 4.3 |
| Red maple | 100 | 125 | 1.2 | 5.4 |
| Yellow-poplar | 75 | 87 | 1.2 | 4.4 |
| Hickory | 125 | 150 | 1.2 | 3.4 |
| Sourwood | 100 | 212 | 2.1 | 6.9 |
| Other hardwoods | 996 | 1,158 | 1.2 | 4.9 |
| All hardwoods | 3,403 | 4,400 | 1.3 | 4.9 |
| | | PINE MOUNTAIN | | |
| Scarlet oak | 125 | 174 | 1.4 | 4.1 |
| Southern red oak | - | - | - | - |
| White oak | 37 | 50 | 1.4 | 5.5 |
| Post oak | 25 | 37 | 1.5 | 7.5 |
| Other oaks | 25 | 37 | 1.5 | 4.8 |
| Blackgum | 685 | 935 | 1.4 | 4.2 |
| Red maple | 62 | 162 | 2.6 | 10.2 |
| Yellow-poplar | 486 | 586 | 1.2 | 5.3 |
| Hickory | 212 | 262 | 1.2 | 4.4 |
| Sourwood | 25 | 62 | 2.5 | 8.2 |
| Other hardwoods | 985 | 1,321 | 1.4 | 4.5 |
| All hardwoods | 2,667 | 3,626 | 1.4 | 4.7 |

[a] Scarlet oak (Quercus coccinea Muenchh.), southern red oak (Q. falcata Michx.), white oak (Q. alba L.), post oak (Q. stellata Wangenh.), other oaks (Q. spp.), blackgum (Nyssa sylvatica Marsh.), red maple (Acer rubrum L.), yellow-poplar (Liriodendron tulipifera L.), hickory (Carya Nutt. spp.), sourwood (Oxydendron arboreum L.).

[b] Height of tallest tree in the clump if more than one stem.

Average number of trees/clump ranged from 1.0 for post oak at Whetstone to 3.5 for sourwood at Sandy Ford (Table 2). Average number of trees/clump for all hardwoods at the three locations ranged from 1.3 to 1.7. Averages, in this case, can be misleading. Many species, especially the oaks, had numerous sprout clumps of 3 to 5 trees/clump but a high number of individual stems that lowered the average.

Height of all hardwoods at Sandy Ford averaged 5.8 feet compared to 4.9 feet at Whetstone and 4.7 feet at Pine Mountain (Table 2). As a group, the hardwoods were substantially outperformed by planted shortleaf pines (average total height at Sandy Ford was 7.9 feet, at Whetstone 8.4 feet, and at Pine Mountain 9.3 feet). However, certain hardwood species performed better than others. Sourwood averaged approximately 7.0 feet in total

height at Sandy Ford and Whetstone and 8.2 feet at Pine Mountain, and red maple averaged 10.2 feet in total height at Pine Mountain. These are not desirable timber species and provide the most serious competition to pines and desirable hardwoods. Fortunately, their numbers were small.

In addition to planted shortleaf pines and naturally regenerated hardwoods, a certain component of naturally seeded shortleaf pine was found on the three sites. The number of trees/ac ranged from 37 to 75 and average total height ranged from 3.5 to 5.6 feet (Table 3). Although these pines were shorter than their planted counterparts and many hardwoods, they may contribute to the future stand because they occurred mostly in openings in the stand.

Table 3. Number of naturally seeded shortleaf pines/ac at three locations four years after regeneration.

| Location | Trees/ac | Total height |
|---|---|---|
| Sandy Ford | 50 | 5.5 |
| Whetstone | 37 | 3.5 |
| Pine Mountain | 75 | 5.6 |

## SUMMARY AND CONCLUSIONS

After 4 growing seasons, shortleaf pine-hardwood mixed stands developed through low intensive site preparation and burning are beginning to show real promise. Planted pines are averaging 7.9 to 9.3 feet in height and 1.6 to 2.2 inches in basal diameter. Competing hardwoods are not as tall, but many oaks and other commercial hardwoods are well developed and should contribute to the final stand. With new technology leading us toward increases use of hardwoods (Ince 1986), low cost regeneration techniques that allow hardwoods to develop with pines make good sense. Landowners need low cost regeneration alternatives such as this and many place high value on the nontimber benefits these stands can provide.

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# COPPICE REGENERATION IN THE OAK-PINE TYPE RELATIVE TO INITIAL SPECIES COMPOSITION, STAND STRUCTURE, AND SEASON OF FELLING[1/]

James W. McMinn[2/]

Abstract.--Oak-pine stands in the Upper Piedmont of Georgia were harvested with feller-bunchers in both the dormant season and early growing season to 1-inch and 4-inch lower diameter limits. The initial hardwood component was comprised primarily of scarlet oak (Quercus coccinea Muenchh.), post oak (Q. stellata Wangenh.), black oak (Q. velutina Lam.), chestnut oak (Q. prinus L.), southern red oak (Q. falcata Michx.), hickory (Carya spp.), blackjack oak (Q. marilandica Muenchh.), sourwood (Oxydendrum arboreum (L.) DC.), white oak (Q. alba L.), dogwood (Cornus florida L.), and blackgum (Nyssa sylvatica Marsh.), respectively, as indicated by basal area. Analysis of variance was employed to test the influence of species, as well as season of felling, degree of stand removal, and their interactions on 5-year coppice growth. Five years after the 4-inch-limit harvest, coppice coverage per square foot of initial stand basal area was only 41 percent as great as after the 1-inch limit harvest. Species predominance in the 5-year coppice stand differed substantially from the initial stand due to species differences in coppice regrowth per square foot of initial basal area.

## INTRODUCTION

This study was motivated by the potential for using intensive whole-tree harvesting as a silvicultural tool (Butts and Preston 1979). The general objective was to compare the effects of season and intensity of whole-tree harvesting on subsequent stand development in mixed hardwood-pine associations of the Upper Piedmont. An earlier paper presented the effects of the treatment variables on total sprout coverage and its relation to pine regeneration through the fourth growing season (McMinn 1985a). The original study was not designed to test differences in coppicing among species or the interactions of species with the harvesting variables. Nevertheless, such a test was devised, and this paper presents results based on the 5-year-old coppice component.

## METHODS

The study area is in the Upper Piedmont of Georgia on the Dawson Forest, which is managed by the Georgia Forestry Commission. Detailed site and stand characteristics were presented earlier. Table 1 presents average initial stand composition by general species group and size class. One-acre treatment plots were harvested using a typical whole-tree system that included a small feller-buncher and grapple-skidders. Harvesting removed all material down to 4-inch or 1-inch diameter limits in both January and June of 1980. Each combination of season and intensity was replicated three times in a completely randomized design. Detailed observations and measurements were confined to the interior 0.5 acre of each 1-acre plot.

Coppice regrowth was characterized from a 100-percent inventory of sprout clumps that were at least 4.5 feet tall after the fifth growing season (virtually all clumps). Sprout clump coverage per acre was calculated from estimates of the average crown diameter at the height of maximum crown spread. This value is essentially an aggregation of clump crown projections by species.

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Table 1.--Initial stand basal area by species group and size class

| Species group | Size class[1/] Sapling | Pulpwood | Sawtimber |
|---|---|---|---|
| | - - - - - | ft$^2$/acre | - - - - - |
| Pine | 7 | 15 | 3 |
| Red oaks | 5 | 8 | 12 |
| White-post-chestnut oak | 5 | 6 | 8 |
| Other hard hardwoods | 4 | 2 | 2 |
| Soft hardwood | 1 | 1 | 1 |
| Shrub | 1 | - | - |
| Miscellaneous | 6 | 3 | 1 |
| All Species | 29 | 35 | 27 |

1/ Saplings 0.5-4.5 inches d.b.h., pulpwood 4.6-9.5 inches, sawtimber 9.6 inches minimum d.b.h.

Since the original design focused on stand development of species mixtures, rather than individual trees or species, all species did not occur on all plots. However, 11 species were represented on all plots in the coppice stands as well as the initial stands. They were (in order of initial stand basal area) scarlet oak, post oak, black oak, chestnut oak, southern red oak, hickory, blackjack oak, sourwood, white oak, dogwood, and blackgum. These species occurred in varying proportions from plot-to-plot. To reduce species response to an equivalent basis, coppicing was expressed as the following ratio:

$CR_i = CV_i/BA_i$, where
CR = coppicing ratio,
CV = square feet per acre of fifth-year coppice crown coverage,
BA = square feet per acre of basal area in the initial stand,
i = $i^{th}$ species

The calculated coppicing ratios were subjected to analysis of variance. To compare relative sprouting potential among species, an index--the quotient of two coppicing ratios--was calculated for species pairs.

## RESULTS AND DISCUSSION

Coppice coverage per square foot of initial basal area was significantly affected by intensity of harvesting and by species (Table 2). Significantly more coppice coverage might have resulted from the dormant season harvesting, but seasonal effects were confounded by heavy pine natural regeneration following dormant-season harvesting only (McMinn 1985a). Differences by season were nonsignificant as were all possible interactions. The coppicing ratio was 382 square feet of crown coverage per square foot of initial basal area for 1-inch limit harvesting versus only 158 for 4-inch limit plots. The difference is attributed to competition from the residual stems in the 4-inch-limit treatment, rather than to a larger number of potential sprouting stumps in the 1-inch-limit harvesting. Early in the study, there was evidence that the residual stands offered substantial competition to both hardwood coppice and pine regeneration (McMinn 1985b). A very high proportion of the smaller stumps were completely destroyed in the 1-inch-limit harvesting operation.

Table 2.--Analysis of variance results for coppice coverage per unit of initial stand basal area

| Source | df | F | Prob > F |
|---|---|---|---|
| Season | 1 | 1.90 | 0.1714 |
| Intensity | 1 | 21.77 | 0.0001 |
| Species | 10 | 3.78 | 0.0003 |
| Season x intensity | 1 | 1.04 | 0.3100 |
| Season x species | 10 | 0.57 | 0.8332 |
| Intensity x species | 10 | 1.03 | 0.4217 |
| Sea. x int. x spec. | 10 | 0.95 | 0.4891 |

Coppicing ratio by species ranged from 558 down to 74 (Table 3). Percentage distributions in sapling, pulpwood, and sawtimber classes give no indication that the species differences are due to size. In some species, however, sprouting potential appears to vary with size or age as reflected by size (Johnson 1975, Johnson 1977). The two most prolific sprouters, dogwood and sourwood, are inherently small species, as is the least prolific, blackjack oak. There is no apparent trend in any of the size classes as the coppicing ratio changes among the other species.

Table 3.--Coppicing ratio and percentage distribution of initial stand basal area by general size class for eleven species in the Upper Piedmont

| | Coppicing ratio | Size Class Sapling | Pulpwood | Sawtimber |
|---|---|---|---|---|
| | | - - - - | percent | - - - - - |
| Dogwood | 558 | 88 | 12 | 0 |
| Sourwood | 497 | 88 | 10 | 2 |
| White oak | 354 | 20 | 20 | 60 |
| Chestnut oak | 318 | 20 | 26 | 54 |
| Blackgum | 291 | 34 | 42 | 24 |
| Southern red oak | 241 | 22 | 38 | 40 |
| Scarlet oak | 214 | 16 | 27 | 57 |
| Black oak | 169 | 26 | 31 | 43 |
| Hickory | 155 | 29 | 29 | 42 |
| Post oak | 98 | 36 | 43 | 21 |
| Blackjack oak | 74 | 42 | 50 | 8 |

Table 4 indicates a substantial potential for species predominance to change in coppice stands compared to initial stands, even among closely ranked sprouters occurring in this study. For example, among the five most prolific sprouters, dogwood produced almost 60 percent more coppice coverage than white oak per square foot of initial basal area and white oak produced 22 percent more than blackgum. Among the five species occupying the middle range, chestnut oak produced 32 percent more coppice than southern red oak and southern red oak produced 43 percent more than black oak. Among the five least prolific sprouters, scarlet oak produced 38 percent more than hickory and hickory produced over twice as much as blackjack oak.

Very obvious potentials for species shifts are apparent when the coppicing of our five most prolific and least prolific species are compared (Table 5). In the most extreme case, dogwood produced over seven and a half times as much sprout coverage as blackjack oak per square foot of initial basal area, and sourwood produced almost seven times as much as blackjack oak. However,

even though these two species resprout vigorously, they will ultimately become understory or midstory components. Among the species that will ultimately form the dominant overstory, white oak production was over three and a half times as much as post oak and almost five times as much as blackjack oak. Similarly, chestnut oak was over three times as prolific as post oak and over four times as prolific as blackjack oak.

Table 4.--Quotients of coppicing ratios between species pairs for species exhibiting high to low sprouting tendencies (based on coppicing ratios for all study treatments)

(a) High range

| Species[1/] | : | DOWO | SOWO | WHOA | CHOA | BLGU |
|---|---|---|---|---|---|---|
| DOWO | : | 1 | .89 | .63 | .57 | .52 |
| SOWO | : | 1.12 | 1 | .71 | .64 | .59 |
| WHOA | : | 1.58 | 2.40 | 1 | .90 | .82 |
| CHOA | : | 1.75 | 1.56 | 1.11 | 1 | .92 |
| BLGU | : | 1.92 | 1.71 | 1.22 | 1.09 | 1 |

(b) Middle range

| Species | : | CHOA | BLGU | SROA | SCOA | BLOA |
|---|---|---|---|---|---|---|
| CHOA | : | 1 | .92 | .76 | .67 | .53 |
| BLGU | : | 1.09 | 1 | .83 | .74 | .58 |
| SROA | : | 1.32 | 1.21 | 1 | .89 | .70 |
| SCOA | : | 1.49 | 1.36 | 1.13 | 1 | .79 |
| BLOA | : | 1.88 | 1.72 | 1.43 | 1.27 | 1 |

(c) Low range

| Species | : | SCOA | BLOA | HICK | POOA | BJOA |
|---|---|---|---|---|---|---|
| SCOA | : | 1 | .79 | .72 | .46 | .35 |
| BLOA | : | 1.27 | 1 | .92 | .58 | .44 |
| HICK | : | 1.38 | 1.09 | 1 | .63 | .48 |
| POOA | : | 2.18 | 1.72 | 1.58 | 1 | .76 |
| BJOA | : | 2.89 | 2.28 | 2.09 | 1.32 | 1 |

[1/] BJOA = blackjack oak, BLGU = blackgum, BLOA = black oak, CHOA = chestnut oak, DOWO = dogwood, HICK = hickory, POOA = post oak, SCOA = scarlet oak, SOWO = sourwood, SROA = southern red oak, WHOA = white oak.

Table 5.--Quotients of coppicing ratios between species pairs for species exhibiting high and low sprouting tendencies

| Species | : | DOWO | SOWO | WHOA | CHOA | BLGU |
|---|---|---|---|---|---|---|
| SCOA | : | 2.61 | 2.32 | 1.65 | 1.49 | 1.36 |
| BLOA | : | 3.30 | 2.94 | 2.09 | 1.88 | 1.72 |
| HICK | : | 3.60 | 3.21 | 2.28 | 2.05 | 1.88 |
| POOA | : | 5.69 | 5.07 | 3.61 | 3.24 | 2.97 |
| BJOA | : | 7.54 | 6.72 | 4.78 | 4.30 | 3.93 |

The foregoing figures on relative coppicing should be interpreted as tendencies towards species shifts, rather than indices of ultimate dominance. The predominance of a species in the coppice regrowth is a product of the interaction between coppicing potential and predominance in the initial stand. In addition, sprout mortality may be a factor in the ultimate species dominance within a stand (Johnson 1977). Table 6 presents the overall shifts in ranking for the species occurring in this study. As a result of the differential coppicing, only 4 of the 11 species remained within one position of their original ranking. As might be expected, dogwood and sourwood underwent the most drastic shifts upward (6 and 5 positions, respectively). Even though these species will ultimately occupy the midstory, their predominance at the coppice stage probably influences the ultimate predominance of different overstory species via species variation in competitive capacity at the coppice stage. Hickory, post oak, and blackjack oak shifted downwards three, five, and three positions, respectively. Since these are the least desirable of the overstory species, complete removal of all woody biomass should result in some upgrading of the subsequent stands.

Table 6.--Coppicing ratio, percent of initial stand basal area, percent of coppice coverage, initial stand rank, and coppice stand rank by species

| Species | Coppicing ratio | Percent of: Stand | Percent of: Coppice | Rank: Stand | Rank: Coppice |
|---|---|---|---|---|---|
| Dogwood | 558 | 4 | 10 | 10 | 4 |
| Sourwood | 497 | 8 | 12 | 8 | 3 |
| White oak | 354 | 5 | 6 | 9 | 8 |
| Chestnut oak | 318 | 10 | 16 | 4 | 1 |
| Blackgum | 291 | 2 | 3 | 11 | 11 |
| Southern red oak | 241 | 10 | 9 | 5 | 6 |
| Scarlet oak | 214 | 16 | 16 | 1 | 2 |
| Black oak | 169 | 12 | 9 | 3 | 5 |
| Hickory | 155 | 9 | 5 | 6 | 9 |
| Post oak | 98 | 14 | 7 | 2 | 7 |
| Blackjack oak | 74 | 8 | 3 | 7 | 10 |

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# Even-Aged Regeneration Alternatives for Low Quality Mixed Hardwood Forests in the Virginia Piedmont[1]

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Abstract.-- The effects of site quality, harvest season, and four regeneration treatments on natural hardwood and planted loblolly pine (Pinus taeda L.) growth and density are evaluated three years after clear felling. Low-quality stems and poor species composition characterized six similar pairs of plots randomly selected for dormant or growing season harvests. The four regeneration treatments were (1) clear felling and whole-tree harvest only; (2) clear felling and whole-tree harvest with planted loblolly pine seedlings; (3) clear felling, herbicide treatment of all hardwood stumps at time of felling, and pine planting; (4) clear felling, stump treatment at time of felling, pine planting, and an herbicide pine release after one growing season. Natural regeneration growth was significantly greater with a dormant season harvest, while planted pine growth was significantly greater with a growing season harvest. The reduced amount of hardwood regeneration resulting from the herbicide treatments was accompanied by an increase in pine growth.

## INTRODUCTION

A significant amount of the Virginia forest resource is in the Piedmont Physiographic Province which contains 2.5 million hectares of private and industrial commercial forest land (Brown 1986). Over one million hectares, 72% of Virginia Piedmont forests, are composed of upland hardwoods and oak-pine forest types (Brown 1985,1986). The potential for wood production of these forests is severely limited by an abundance of low quality stems and undesirable species. The 1977 U.S.D.A. forest inventory in the Virginia Piedmont found 75% of these forests are understocked with 20% of the stocking in rotten and poorly formed trees (Knight and McClure 1978). Poor stand conditions are largely a result of natural succession from farmland following abusive agricultural practices, continuous detrimental high-grading, and wildfire (Smith and Linnartz 1980). A recent finding that planted pines represent only 4% of the total biomass in Piedmont forests suggests that a lack of pine regeneration is also a problem limiting forest productivity (Bechtold and Phillips 1985).

The large area represented by upland hardwood and oak-pine forest types, the inferior quality of these stands, and the very small portion of Piedmont forests in pine plantations points to the need for developing even-aged silvicultural guidelines that can convert low quality hardwood stands into productive hardwood, mixed hardwood-pine, or pine forests. Land ownership patterns in the Piedmont are also influential in the design of appropriate silvicultural systems. Because 81% of Virginia Piedmont forests are composed of small, privately owned woodlands, regeneration alternatives must be developed that are applicable over a wide range of landowner objectives, tract sizes, and management intensities (Bechtold and Phillips 1985).

The objective of this ongoing study is to formulate even-aged regeneration alternatives appropriate for a variety of woodland owners in the Virginia Piedmont. In this paper, the effects of site quality, season of harvest, and 4 even-aged regeneration treatments on natural hardwood and planted loblolly pine growth, and density are evaluated 3 years following clear felling and whole-tree removal in Virginia Piedmont mixed oak stands.

## METHODS

### Study Area

The study site is located in the Virginia Piedmont at Virginia Polytechnic Institute and

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State University's Reynolds Homestead Research Center, near Critz, VA. The soils are leached, eroded Ultisols developed mainly from granitic and metamorphic bedrock. Slopes range from 2-20% with 6-8% being most common. Annual precipitation averages 125 centimeters and is well distributed through the year. The frost free season averages 196 days (Crockett 1973).

The plots were located in 50-80 year-old second growth oak-hickory forests on site qualities ranging from site index 15-23 meters (base age 50) for white oak (Quercus alba L.) (Carmean 1971, Doolittle 1975). Pre-harvest stands contained an average of 24.3 square meters of basal area per hectare on the poorer sites, and 27.0 square meters of basal area per hectare on the better sites. Oak species comprised about 59% of the basal area on the poorer sites, and 34% on the better sites. The dominant species found on poorer sites included chestnut oak (Quercus prinus L.), scarlet oak (Quercus coccinea Muenchh.), red maple (Acer rubrum L.), and sourwood (Oxydendrum arboreum (L.) DC), with scattered Virginia pine (Pinus virginiana Mill.), and white pine (Pinus strobus L.). White oak, yellow-poplar (Liriodendron tulipifera L.), red maple, sourwood, and northern red oak (Quercus rubra L.). dominated the better sites with smaller amounts of scarlet oak, and American beech (Fagus grandifolia Ehrh.).

Study Design

The study contains 3 blocks, and is a split-split plot design. Each block contains 2 site classes, good and poor, representing the main plot. Site indices range from 15-19 meters for white oak (base age 50) on poor sites, and 20-23 meters for white oak (base age 50) on good sites (Carmean 1971, Doolittle 1975).

Each half of the main plots was randomly assigned a dormant or growing season harvest, representing the first split. The dormant season harvest was completed between 17 February and 29 April, 1983. The growing season harvest was accomplished between 6 June and 11 August, 1983.

The determination of treatment effects was accomplished by subdividing each site class-harvest season unit into four 30 meter by 30 meter plots representing the second split. Each split-split plot was randomly assigned one of the following four treatments:

T1) Clear felling and whole-tree harvest only.

T2) Clear felling and whole-tree harvest, and planted loblolly pine seedlings.

T3) Clear felling and whole-tree harvest, herbicide treatment of all hardwood stumps, and planted loblolly pine seedlings.

T4) Clear felling and whole-tree harvest, herbicide treatment of all hardwood stumps, planted loblolly pine seedlings, and a release treatment of pine seedlings.

Each regeneration treatment employed a clear felling whole-tree harvest. All stems greater than 2.5 centimeters dbh were felled within 15 centimeters of ground level.

Treatments 2, 3, and 4 included planting genetically improved 1-0 loblolly pine seedlings from a Virginia Piedmont source in March 1984. Seedlings were hand planted on a 2 meter by 2 meter grid resulting in a density of 2500 seedlings per hectare.

The cut-stump herbicide treatment used in Treatments 3 and 4 consisted of a thin stream of undiluted herbicide applied to the cambial region of the stump immediately following cutting. All hardwood stumps were treated at an average rate of 0.27 liters per square meter of basal area. Triclopyr (3,5,6-trichloropyridinyloxyacetic acid as Garlon-4®61.6% EC), glyphosate (N-phosphonomethyl glycine as Roundup® 41.0% SL), dicamba (3,6-dichloro-o-anisic acid as Banvel CST® 10.6% SL), and picloram (4-amino-3,5,6-trichloropicolinic acid as Tordon-101® 5.4% SL) were used for the cut-stump treatment (Zedaker et al. in press).

Treatment 4 plots received a pine release in March 1985. Plots were randomly split so that each half received a basal bark spray, or a soil applied herbicide release treatment.

The basal bark spray release method consisted of 4% triclopyr (ester) (as Garlon-4® 61.6% EC) diluted with diesel fuel and applied with a backpack sprayer. The mixture was applied to the bottom 15-20 centimeters of treated stems until runoff. All stems within 1 meter of loblolly pine seedlings were treated. An average of 3.4 liters of triclopyr and 82 liters of diesel fuel were used to release 1300 loblolly pines per hectare. An average of 11.6 man-hours was required to treat 1 hectare.

The soil active herbicide was applied as 50% hexazinone (3-cyclohexyl-6-(dimethylamino) -1-methyl 1-1,3,5-triazine-2,4(1H,3H)dione as Velpar L® 25% SL) in water with a spotgun. The mixture was applied in 6 evenly spaced 2.5 milliliter spots arranged in a 1 meter radius circle around each loblolly pine seedling. An average of 9.7 liters of hexazinone was used to release 1300 loblolly pines per hectare. The time required to treat 1 hectare averaged 6.6 man-hours.

Sampling Procedure

Natural regeneration was sampled at the end of the 1985 growing season in all 4 treatments. Nine randomly located 2 meters x 2 meters plots were sampled in each 30 meters x 30 meters treatment plot. All natural regeneration taller than 25 centimeters was tallied for a) species, b) total height, and c) two crown diameters taken at right angles to each other from terminal bud to terminal bud.

Loblolly pine growth was also measured at the end of the 1985 growing season. All surviving loblolly pines were measured for a) total height, and b) groundline diameter.

Analysis

The effects of site quality, season of harvest, and the 4 regeneration treatments on natural regeneration total crown volume (crown volume=heightx3.14x(crown radius)$^2$) were examined using split-split plot analysis of variance (ANOVA). An alpha level of 0.05 was used for all significance tests.

ANOVA was performed on the density of free-to-grow natural regeneration crop and non-crop species. If height was greater than 1.25 times the mean height of all regeneration in a treatment plot, an individual was considered free-to-grow. Density was defined as the number of free-to-grow trees per hectare. Crop species included pignut hickory (Carya glabra Mill.), mockernut hickory (Carya tomentosa Poir. Nutt.), yellow-poplar, white oak, scarlet oak, chestnut oak, and northern red oak. Free-to-grow non-crop species included tree-of-heaven (Ailanthus altissima Mill.), red maple, flowering dogwood (Cornus florida L.), blackgum (Nyssa sylvatica Marsh.), sourwood, sassafras (Sassafras albidum Nutt.), black locust (Robinia pseudoacacia L.), black cherry (Prunus serotina Ehrh.), and American beech.

The effects of site quality, season of harvest, and 3 regeneration treatments on planted loblolly pine total crown volume was analyzed using ANOVA and Duncan's MRT. Crown volume was estimated from groundline diameter using a linear equation developed by Zedaker and others (in prep.). ANOVA is also performed on the density of free-to-grow loblolly pines. If height was greater than the mean height of all natural regeneration in the treatment plot, a planted loblolly pine was considered free-to-grow.

RESULTS AND DISCUSSION

Natural Hardwood Regeneration

The good site class averaged 10,978 cubic meters of natural hardwood crown volume per hectare, while the poor site class averaged 10,944 cubic meters per hectare. The density of free-to-grow crop species was also similar between site classes, 1,957 stems per hectare and 1,806 stems per hectare on good and poor sites, respectively. However, free-to-grow, non-crop species were nearly twice as numerous on the good site class, 3,068 stems per hectare, than on the poor site class, 1,759 stems per hectare.

Total hardwood crown volume was significantly greater with a dormant season harvest, 14,442 cubic meters per hectare, than with a growing season harvest, 7,780 cubic meters per hectare. The larger size of hardwood regeneraton after a dormant season harvest was probably a result of the greater carbohydrate reserves stored in dormant tree roots (Roth and Hysting 1943) and the better growing conditions available to all regeneration when the overstory was removed before the spring growing season. The density of free-to-grow crop species was greater with a dormant season harvest, 2,084 stems per hectare, than with a growing season harvest, 1,678 stems per hectare. The density of free-to-grow non-crop species was also greater with a dormant season harvest, 2,709 stems per hectare, than with a growing season harvest, 2,118 stems per hectare.

Treatments 1 and 2 contained similar amounts of hardwood crown volume, but total hardwood crown volume was significantly reduced by the herbicide cut-stump treatment in Treatment 3, and further reduced by the herbicide cut-stump treatment and pine release in Treatment 4 (Table 1). The density of free-to-grow crop and non-crop species was significantly affected by the regeneration treatments

Table 1: Natural regeneration total crown volume by regeneration treatment, harvest season, and site class after 3 growing seasons.

| Regeneration Treatment | SITE CLASS: POOR — Season of Harvest: Dormant | POOR: Growing | GOOD: Dormant | GOOD: Growing | Total Crown Volume |
|---|---|---|---|---|---|
| | Crown volume ($m^3$/ha) a/ | | | | b/ |
| Clearcut | 19,328abc | 11,393cdef | 18,234abc | 15,766abcd | 16,180A |
| Clearcut,Pine | 21,624a | 8,786defg | 19,790ab | 13,254bcde | 15,864A |
| Clearcut,Stump Treatment,Pine | 14,490abcd | 6,261efg | 9,094defg | 4,194fg | 8,510B |
| Clearcut,Stump Treatment, Pine, Release | 4,579fg | 1,181g | 6,088efg | 1,402g | 3,312C |

a/ - Across all seasons of harvest and site classes, treatment means followed by the same letter are not significantly different at alpha=0.05 (Duncan's Multiple Range Test).
b/ - Overall regeneration treatment means followed by the same letter are not significantly different at alpha = 0.05 (Duncan's Multiple Range Test).

Table 2: Density of free-to-grow hardwood crop species by regeneration treatment, harvest season, and site class after 3 growing seasons.

| Regeneration Treatment | SITE CLASS POOR — Season of Harvest: Dormant | Growing | GOOD: Dormant | Growing | Total Density |
|---|---|---|---|---|---|
| | Density (no/ha) | | | | |
| Clearcut | 1,481a | 1,296a a/ | 2,973a | 1,297a | b/ 1,726AB |
| Clearcut,Pine | 1,481a | 741a | 1,018a | 1,760a | 1,250B |
| Clearcut,Stump Treatment,Pine | 2,131a | 2,037a | 2,131a | 2,037a | 2,060AB |
| Clearcut,Stump Treatment, Pine, Release | 2,407a | 2,871a | 3,056a | 1,482a | 2,454A |

a/ - Across all seasons of harvest and site classes, treatment means followed by the same letter are not significantly different at alpha=0.05 (Duncan's Multiple Range Test).
b/ - Overall regeneration treatment means followed by the same letter are not significantly different at alpha = 0.05 (Duncan's Multiple Range Test).

Table 3: Density of free-to-grow non-crop species by regeneration treatment, harvest season, and site class after 3 growing seasons.

| Regeneration Treatment | SITE CLASS POOR — Season of Harvest: Dormant | Growing | GOOD: Dormant | Growing | Total Density |
|---|---|---|---|---|---|
| | Density (no/ha) | | | | |
| Clearcut | 2,223bcde | 2589abcd a/ | 3243abc | 3427ab | b/ 2870A |
| Clearcut,Pine | 1,389de | 1574cde | 3519ab | 1574cde | 2013B |
| Clearcut,Stump Treatment,Pine | 2778abcd | 1389de | 4074a | 2870abcd | 2779A |
| Clearcut,Stump Treatment, Pine, Release | 1389de | 741e | 3056abcd | 2778abcd | 1991B |

a/ - Across all seasons of harvest and site classes, treatment means followed by the same letter are not significantly different at alpha=0.05 (Duncan's Multiple Range Test).
b/ - Overall regeneration treatment means followed by the same letter are not significantly different at alpha = 0.05 (Duncan's Multiple Range Test).

(Tables 2 and 3). The relatively high density of free-to-grow natural regeneration in Treatment 3 and 4 plots, despite the herbicide treatments, attested to the abundance of natural regeneration typical in these clearcuts, particularly on the good site class.

Examination of total hardwood crown volume (Table 1) revealed that for all site class-regeneration treatment combinations, hardwood growth was greater with a dormant season harvest. On both site classes, greatest growth occurred when the harvest was performed during the dormant season and no herbicide treatments were applied. The herbicide cut-stump treatment, and the herbicide cut-stump treatment plus pine release resulted in less growth of natural hardwood regeneration when applied in treatment plots which received a growing season harvest.

The density of free-to-grow crop and non-crop species was much less influenced by harvest season and regeneration treatment than natural regeneration size. Hardwood distribution was probably more influenced by pre-harvest stand composition and seed dispersion from adjacent stands. Because non-crop species were generally more densely distributed than crop species, intermediate stand treatments may be needed to favor crop trees.

<u>Planted Loblolly Pine</u>

Nearly twice as much total loblolly pine crown volume was found on the poor site class, 484.4 cubic meters per hectare, than on the good site class, 263.3 cubic meters per hectare. The inverse relationship between total loblolly pine volume index and site index at age 2 appears to be par-

Table 4: Planted pine regeneration total crown volume by regeneration treatment, harvest season, and site class after 2 growing seasons.

| Regeneration Treatment | SITE CLASS POOR | | GOOD | | Total Basal Area |
|---|---|---|---|---|---|
| | Season of Harvest | | | | |
| | Dormant | Growing | Dormant | Growing | |
| | Crown volume ($m^3$/ha) | | | | |
| Clearcut,Pine | 136.1ef a/ | 578.4b | 46.8f | 294.2de | b/ 263.9B |
| Clearcut,Stump Treatment,Pine | 224.0def | 620.9b | 85.9f | 369.9cd | 325.2B |
| Clearcut,Stump Treatment, Pine, Release | 382.8cd | 964.3a | 221.6def | 561.5bc | 532.6A |

a/ - Across all seasons of harvest and site classes, treatment means followed by the same letter are not significantly different at alpha=0.05 (Duncan's Multiple Range Test).
b/ - Overall regeneration treatment means followed by the same letter are not significantly different at alpha = 0.05 (Duncan's Multiple Range Test).

tially a result of the greater density of competing natural regeneration on the good site class. The more uniform shading from the more densely distributed natural regeneration on the good site class resulted in smaller individual loblolly pine crown volume, 0.26 cubic meters, than on the poor site class, 0.48 cubic meters. However, similar numbers of free-to-grow pines occupied the good and poor site classes, 862 per hectare and 928 per hectare, respectively.

Treatment plots harvested during the growing season contained significantly more loblolly pine crown volume, 564.9 cubic meters per hectare, than those harvested during the dormant season, 182.9 cubic meters per hectare. The greater pine growth was probably a result of the significantly smaller amount of natural regeneration crown volume found in growing season harvest plots. The significantly larger number of free-to-grow planted pines following a growing season harvest, 1486 stems per hectare, compared to only 306 trees per hectare with a dormant season harvest, suggested that harvest season effects on loblolly pine growth at age 2 will persist as the stand develops.

Greater growth and more free-to-grow loblolly pines also resulted because the herbicide treatments reduced competition from natural hardwood regeneration. Significantly more total crown volume (Table 4) and free-to-grow pines(Table 5) developed with the use of the herbicide cut-stump treatment and pine release, than with the herbicide cut-stump treatment only or no control

A comparison of loblolly pine regeneration in all 3 regeneration treatments revealed that, on both site classes, total crown volume (Table 4), and

Table 5: Density of free-to-grow loblolly pine by regeneration treatment, harvest season, and site class after 2 growing seasons.

| Regeneration Treatment | SITE CLASS POOR | | GOOD | | Total Density |
|---|---|---|---|---|---|
| | Season of Harvest | | | | |
| | Dormant | Growing | Dormant | Growing | |
| | Density (no/ha) | | | | |
| Clearcut,Pine | 52e a/ | 1266bc | 15e | 1177bc | b/ 628B |
| Clearcut,Stump Treatment,Pine | 385de | 1363ab | 89e | 1444ab | 820B |
| Clearcut,Stump Treatment, Pine, Release | 748cd | 1755ab | 548de | 1903a | 1238A |

a/ - Across all seasons of harvest and site classes, treatment means followed by the same letter are not significantly different at alpha=0.05 (Duncan's Multiple Range Test).
b/ - Overall regeneration treatment means followed by the same letter are not significantly different at alpha = 0.05 (Duncan's Multiple Range Test).

density of free-to-grow trees (Table 5) was significantly greater with a growing season harvest. On both site classes a growing season harvest with no herbicide treatments, resulted in more crown volume and free-to-grow loblolly pines than a dormant season harvest with the herbicide cut-stump treatment plus pine release used in Treatment 4. Conversion of mixed hardwood stands to planted loblolly pine was much more difficult if the preceeding stand was harvested during the dormant season.

## SUMMARY

Natural hardwood regeneration crown volume was similar on both site classes but density was greater on the good site class than on the poor site class. Planted loblolly pine growth, expressed as pine crown volume, was almost 2 times greater on the poor site class, due partially to the less densely distributed hardwood competition. On the good site class the density of non-crop species far exceeded crop species, indicating that a cleaning or crop-tree release may be warranted. These results suggest that site quality is an important consideration when choosing a regeneration system.

Harvest season also affected planted loblolly pine and natural hardwood regeneration differently. Natural hardwood regeneration was favored with a dormant season harvest while planted pines exhibited greater growth following a growing season harvest. These findings indicate that the timing of a clear felling regeneration treatment can be used as an important basic silvicultural tool.

The addition of planted pines in Treatment 2 did not significantly reduce natural regeneration growth from that found on Treatment 1 plots. The cut-stump herbicide treatment effectively reduced natural hardwood regeneration growth as exhibited by reduced total crown volume. Addition of a pine release resulted in even greater natural regeneration control. The reduction in hardwood growth with the herbicide treatments was accompanied by an increase in planted pine growth. The effectiveness of the herbicide treatments was greatly enhanced by a growing season harvest.

## CONCLUSIONS

When a clear felling and whole-tree harvest only was used in upland mixed hardwood stands it appeared that stocking and species composition did not change drastically from the pre-harvest stand. A dormant season harvest can be used to accelerate the growth and establishment of natural regeneration. Species composition can be influenced at the time of clear felling if undesired hardwood stumps are treated with an herbicide.

Planted loblolly pines were favored over natural regeneration if a growing season harvest was used. Herbicide treatments can also be used to favor planted pine regeneration. The larger pine crown volume on the poor site class at age 2 suggested that planted pine regeneration was more easily established on lower quality sites.

The findings of this study encouraged the possibility of regenerating mixed natural hardwood-planted pine. A growing season harvest can be used to favor the establishment of planted pine regeneration over natural regeneration. Three years after clear felling, it appeared that free-to-grow pines will become a component of the future stand, supplementing the stocking of natural regeneration.

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# EVALUATION OF SAMPLING METHODS TO ESTIMATE THE LEVEL OF COMPETING HARDWOOD VEGETATION IN YOUNG LOBLOLLY PINE PLANTATIONS[1]

D. R. WEISE AND G. R. GLOVER[2]

ABSTRACT.--Performance of 42 sampling rules was tested by computer simulation using 24 artificial hardwood rootstock populations of varying density and spatial pattern. Sampling rules were evaluated using relative bias, relative precision, variance, and consistency as criteria. All fixed area and polyareal estimates were unbiased, but Batcheler's triple distance estimates were affected by sampling intensity and biased by spatial pattern. Polyareal methods had greater relative precision, lower variance, and greater consistency than fixed area methods. Horizontal line sampling (crown diameter factor = 100 ft) is recommended as the "best" method for quantifying competing hardwood vegetation. Field testing to determine practicality is necessary.

## INTRODUCTION

Planted loblolly pine (Pinus taeda L) seedlings grow better in the absence of competing vegetation, as does any agronomic crop. It is often desirable to determine the amount or level of hardwood vegetation in a young plantation in order to evaluate the effectiveness of a site preparation treatment or the need for a pine release operation. Few objective field survey methods exist that are specifically designed to measure hardwood vegetation growing in young loblolly pine plantations in the Southeastern United States. Zutter et al. (1985) identified some of the desirable attributes that such a method should exhibit. These include objectivity, simplicity, compatibility with other surveys, and a wide range of applicability. Such a survey method could supply information for evaluation of site preparation effectiveness, determination of need for pine release, and input into growth and yield models that simulate the effects of hardwood competition on pine yield.

The need for an objective, accurate method is becoming critical as costs of various cultural treatments associated with establishing and maintaining young pine plantations increase. This study was designed to identify one or more operational sampling rules that may be used to estimate the level of competing hardwood vegetation in young loblolly pine plantations through computer simulation.

## METHODS

Several sampling studies have been conducted using computer simulation (i.e. Palley and O'Regan 1961, Kaltenberg 1978). In most cases, the studies have simulated mature forests. Kaltenberg examined the effects of spatial pattern on estimates of stocking and density in seedling stands. No sampling studies of competing hardwood vegetation in pine plantations were found in the literature.

A stand simulator was developed from data collected in 19 loblolly pine plantations and was used to produce artificial hardwood rootstock populations similar to those observed in young loblolly pine plantations in the Piedmont and upper Coastal Plain of Alabama (Weise and Glover, in preparation). Twenty-four 16-acre stands with nominal population densities of 500, 1500, or 2500 rootstocks per acre (low, medium, and high density) and values of Pielou's Nonrandomness Index (Pielou 1977) of 0.6, 1.0, 1.6, and 2.2 (uniform, random, lightly clumped, and heavily clumped) aged 3 or 6 years since planting were used in this study. Total rootstock height was determined by a two parameter left and right truncated Weibull function and crown area was determined as a function of total height.

Six basic random sampling schemes were examined: fixed area plots, horizontal points, horizontal line, vertical point, vertical line, and Batcheler's triple distance method (Warren and Batcheler 1979). All combinations of plot sizes of 0.002, 0.004, and 0.01 acre and of circular, square, and rectangular (4 x 1) plot shapes were tested using a 1 percent sampling

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percentage (9 sampling rules). Horizontal point, horizontal line, vertical point, and vertical line schemes, all variable probability methods, were tested at sampling intensities of 1, 2.5, and 5 points per acre (Grosenbaugh 1958, Husch et al. 1982). All line samples were 50 feet long. Rootstocks were selected in proportion to crown area, crown diameter, total height and total height squared by horizontal point, horizontal line, vertical point, and vertical line sampling rules, respectively. Crown factors (CF) of 100 and 200 square feet (or feet) were selected for the horizontal methods (12 sampling rules). Vertical angles of 30°, 45°, and 60° were selected for the vertical methods (18 rules). Batcheler's method estimates density using 3 distance measures: distance between a sample point and the nearest rootstock, between the 1st rootstock and the rootstock nearest it, and from the 2nd rootstock to the rootstock nearest it (excluding the 1st rootstock). This method was also tested at sampling intensities of 1, 2.5, and 5 points per acre (3 rules). Therefore, a total of 42 sampling rules was evaluated.

Hardwood crown diameter and cross-sectional area were used in this study rather than stem diameter and basal area because of the relatively small stem sizes and the problem with multiple stems per hardwood rootstock common in young pine plantations. Crown measurements may also be good indicators of competitive stress exerted on the pines by the hardwoods. The relatively low sampling percentages (1 percent or 1, 2.5, or 5 sample points per acre) were chosen out of practicality. Although greater sample intensity should yield better results, the practical limitations of time and manpower that would be expended in a field application of these techniques dictate relatively small samples.

Estimates of number of hardwood rootstocks per acre (NRPA), sum of total hardwood rootstock heights per acre (STRH), and sum of hardwood crown areas per acre (SCA) were computed for each stand sample (stand entry). These variables were chosen because they may be used as measures of competition if they are shown to be well correlated with pine growth losses. A stand entry estimate was based on 16, 40, or 80 randomly located sample points (plots). Standard errors of the stand entry estimates were calculated for all sampling methods except for Batcheler's. Sampling ceased after 200 stand entries or if the mean of all stand entry estimates of NRPA did not differ by more than 0.5 percent for 10 consecutive stand entries.[3]

Relative bias (R), variance, percentage of estimates falling within 5 percent of the true value (P5), and consistency of the estimators were used to evaluate the 42 sample rules (Schreuder and Thomas 1985). These criteria were chosen for several reasons. An unbiased sampling rule is desirable. Since variance is used to estimate the sample size necessary to achieve a desired allowable error, low variance is desirable. High precision in a sampling estimator is also desirable. If it is not possible to gather an adequate sample, an estimate from an unbiased high precision method should be sufficient.

R was defined as the ratio of the sample estimate to the true value. Due to the differing populations, variance was expressed as the mean of stand entry standard errors divided by the true value (CV), and consistency (C) was defined as the standard error between stand entry estimates divided by the true value. An analysis of variance (ANOVA) was used to detect spatial pattern, population density, sampling method, and sampling intensity effects on R and P5. The ANOVA was used to identify "robust" sampling rules, i.e. a sampling rule unaffected by spatial pattern or population density.

## RESULTS

In general, the responses of each of the estimators for NRPA, STRH, and SCA with respect to R, PS, CV, and C were similar. For illustrative purposes, NRPA estimators will be discussed.

Relative bias (R) for all fixed area and polyareal methods approached 1. This indicated that the methods were relatively unbiased at low sampling intensity. Based on the ANOVA, estimates using Batcheler's method were significantly (P = 0.01) affected by pattern. R was generally less than 1 for uniform populations and greater than 1 for clumped populations. Other work has shown that more intensive sampling reduces the bias of this method (Batcheler and Hodder 1975).

The ANOVA showed that P5 for the fixed area methods was strongly affected by spatial pattern and population density. P5 was highest for uniform populations and lowest for clumped populations. For example, P5 for 0.01-acre circular plots for 3-year-old, low density populations was 70 percent, 35 percent, 23 percent, and 20 percent (uniform, random, lightly clumped, heavily clumped), respectively. Relative precision (P5) was highest for the polyareal methods. Of the polyareal methods, horizontal line sampling usually had the higher P5 values. In general, increasing population density increased relative precision for all fixed area and polyareal methods. This was due to an increased number of rootstocks being measured at each sample point.

CV for the polyareal methods was lower than for the fixed area methods. As Oderwald (1981) proved, variance was lowest in uniform populations and highest in clumped populations. Increasing population density reduced CV as more rootstocks were sampled at each point. In this study, horizontal and vertical line sampling variances were lower than for the polyareal point sampling rules.

The effects of pattern and sampling intensity on C were similar to those on CV. As sampling

[3] Copies of both sampling and stand simulators are available from either author.

intensity increased, C improved and CV decreased. C was highest for the polyareal methods.

## DISCUSSION AND RECOMMENDATIONS

Increasing the number of rootstocks sampled would have improved the performance of all sampling rules examined. An increased number of rootstocks sampled at each point would have reduced the amount of variation between sample points (CV) and reduced the amount of variation between stand entry estimates (C). This also may have been accomplished by increasing plot sizes, reducing CF's and vertical angles or by increasing the number of sample points per acre.

Fixed area plot estimates are theoretically unbiased and are "workable" in dense stands. Fixed plot boundaries facilitate the selection of sample rootstocks. The relatively poor performance of fixed area methods in comparison to polyareal methods in this study can be attributed to two factors. Fewer rootstocks were sampled in fixed area sampling than in polyareal sampling (Sukwong et al. 1971). Secondly, the plot sizes used may have been too small. Increasing plot sizes to 0.01 acre might have reduced the effects of density and pattern on P5, CV, and C for fixed area plots. However, this may not be practical as the amount of time spent at each sample point would increase substantially. An average of 50 rootstocks would be sampled at each point in the populations with densities of 2500 rootstocks per acre.

Given the conditions of this study, horizontal line sampling (100 CF) appears to be the best method to use to estimate the three variables of interest (Table 1). This study showed that the method is relatively unbiased at low sampling intensities. Additionally, nearly 100 percent of all horizontal line estimates fell within 5 percent of the true value. The coefficient of variation, and consequently the variance, associated with the estimate was the lowest of all methods examined. Thus, horizontal line sampling should require the least number of sample points to achieve a specified allowable error of all methods studied.

The use of horizontal line sampling to provide information about the level of competing hardwood vegetation in loblolly pine plantations is promising. The method is accurate and objective. However, field testing of this method needs to be conducted. Field tests will illustrate the practicality of the method as well as aiding in development of equipment (Cooper 1957). Once this step is completed, the subjectivity that is now often required in plantation evaluation may no longer be necessary.

Table 1.--Performance of sampling rules used to estimate number of rootstocks per acre for a simulated three-year-old, heavily clumped, low density, hardwood rootstock population.

| Sampling Rule[1] | Relative Bias[2] | Relative Precision[3] | Coefficient of Variation[4] | Consistency[5] |
|---|---|---|---|---|
| | | Percent | Percent | Percent |
| C | 0.99 | 20 | 20.3 | 1.5 |
| R | 1.05 | 18 | 21.5 | 1.6 |
| HP | 1.00 | 48 | 6.2 | 1.3 |
| HL | 0.99 | 89 | 3.7 | 0.7 |
| VP | 1.00 | 34 | 14.6 | 2.1 |
| VL | 1.00 | 50 | 6.5 | 1.5 |
| B | 0.85 | 13 | 26.3 | 1.9 |

[1]C - 0.01-acre circular plot (1 percent sampling intensity)
R - 0.01-acre rectangular plot (1 percent sampling intensity)
HP - horizontal point (CF = 100, 5 pt/acre)
HL - horizontal line (CF = 100, 5 pt/acre)
VP - vertical point (vert. ang. = $30^{\circ}$, 5 pt/acre)
VL - vertical line (vert. ang. = $30^{\circ}$, 5 pt/acre)
B - Batcheler's triple distance (5 pt/acre)

[2]Ratio of estimate of mean to true mean

[3]Percentage of estimates within $\pm 5$ percent of true mean

[4]Ratio of average standard error to true mean

[5]Ratio of standard error between stand entry estimates to true mean

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# SIMULATING THE EFFECT OF HARDWOOD ENCROACHMENT ON LOBLOLLY PINE PLANTATIONS [1/]

W. D. Smith and W. L. Hafley [2/]

**"From habit rather than as a result of natural processes we are inclined to conceive of the most desirable forest to be one with fully stocked stands of a preferred species."**

**Ralph W. Marquis (1947)**

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Abstract.--A procedure suggested by Schumacher and Coile for dealing with the effect of hardwood competition is incorporated into a growth and yield model for Loblolly Pine plantations. Their procedure was based on the assumption that the hardwood basal area would effect the pine growth to the same extent as additional pine basal area. That assumption was modified to reflect the difference in basal area carrying capacity between pine and hardwood on the same site. The model simulates the impact of hardwood encroachment by either a decurrent or excurrent species based on, 1) actual pine and hardwood basal area or 2) percent hardwood composition, at any given age. The assumptions and their implied biological responses are discussed. The veracity of the procedure is tested against a 24 year old site preparation study in Fayette, Alabama. An example of an economic evaluation of hardwood control is presented.

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## INTRODUCTION

There has long been an interest in estimating the impact of hardwood on the growth of pine in regard to predicting pine yields. Schumacher and Coile (1960) suggest that one simply add the hardwood basal area to the pine basal area, project the total as pine, and reapportion it to the respective species. The inherent problems in that approach are the implied assumption that pine and hardwood grow at the same rate, hence the relative proportions will remain constant; and that one square foot of hardwood basal area is equivalent to one square foot of pine basal area. However, their suggestion is not all together inappropriate. Given a hardwood growth function and an estimate of the competitive relationship between pine and hardwood their suggestion seems quite rational. Starting from Schumacher and Coile's suggestion we have evolved a simulation procedure for use with pine plantations and which we have incorporated into the North Carolina State University Managed Loblolly Pine Plantation Growth and Yield Simulator.

While there appear to be a number of studies where hardwood in pine stands was of interest a great many of these have inconsistencies of measurement such that tracking of the performance of hardwood over time is not possible. Without a consistent measure of the hardwood component, the interpretation of the pine performance becomes meaningless. In many instances where hardwoods have been treated, there was either no record of how many hardwood were there or whether or not they were killed. In the face of what appears to be conflicting results due to inadequate data recording we had no choice but to develop a rational simulation of the hardwood impact. We will present here our underlying assumptions, the biologic outcomes of those assumptions, an evaluation of the veracity of the model and, finally, an example of an application of the model.

The two most valuable contributions of simulation are the expansion of the applicability of existing knowledge and the identification of gaps in that knowledge. Much of the existing knowledge regarding the impact of hardwood encroachment is of a qualitative nature encorporated into the intuition and experience of a number of foresters. What we present here is the result of discussions we have had with a few of these individuals in which we interacted on our ideas for simulation.

## BASIS FOR SIMULATION

The simulation is based on three models. One, the North Carolina State University Managed Loblolly Pine Growth and Yield Simulator, which we will refer to from here on as "the model" is based on predicting, 1) the minimum, mode, maximum, and standard deviation of height and diameter of

1/ Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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stands over time, where those characteristics are functions of dominant height and growing space following initial survival, and 2) survival, which is a function of dominant height, site index, and growing space. The other two models are hardwood basal area projection models, in which basal area is a function site index, age, and initial basal area.

The two hardwood models are intended to represent different crown shapes. In modeling mixed stands the true ratio's of the species in the mixture must be correctly represented. This ratio is not identical to the ratio of basal areas but more correctly represented by the relative area occupied by their crowns (Assman 1970). Two different hardwood models are required to reflect the different crown area and growth rate of the hardwood species present. The model for a decurrent species is based on the upland oak data published by Zahner and Myers (1984) to which we fit a Richards function (Richards, 1959). The parameters of the Richards function are themselves functions of site index and initial basal area. The model for an excurrent species was developed by Kenney (1984) for bottomland sweet gum based on data of the NCSU Cooperative Hardwood Program and is also a Richards function whose parameters are expressed as functions of site index and initial basal area.

## ASSUMPTIONS

Given the above models we then made several assumptions regarding how hardwood competition would effect the height and diameter growth and the mortality of the pines. The basic approach is an adaptation of the method we used for simulating thinning (Smith and Hafley, 1984). It is based on a very simple assumption developed in South Africa by A. J. O'Conner, 1935 (Burgers, 1971) called the correlated curve trend (CCT) method. O'Conner suggested that the increment in a plantation thinned to n trees per acre will be equal to some coefficient times the increment of an unthinned plantation of the same number of trees per acre. Mathematically this is expressed as

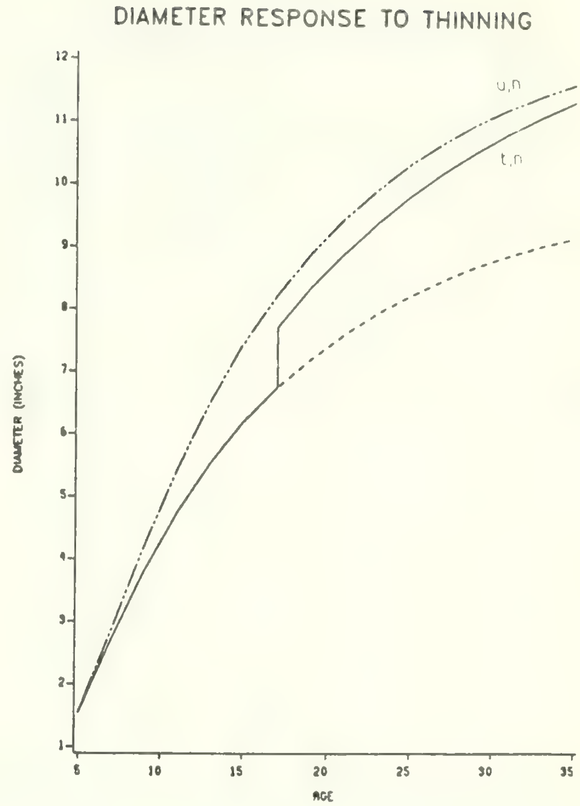
$$I_{(t,n)} = C_r * I_{(u,n)} \quad , \qquad (1)$$

where t = thinned plantation ,
u = unthinned plantations ,
n = trees per acre ,

When applied to basal area per tree increment, $C_r$ can be assumed to be equal to 1. Figure 1 presents a graphical representation of the concept and its impact on average stand diameter.

For the hardwood impact we used the same basic method. We assume that increment in a plantation of n pine trees per acre, with a hardwood component equivalent to m pine trees per acre, will be equal to some coefficient times the increment of a plantation with n + m pine trees per acre and no hardwood component. Mathematically this is represented as

Figure 1.




$$I_{(h,\ n)} = C_r * I_{(u,\ n\ +\ m)} \quad , \qquad (2)$$

where h = plantation with hardwood ,
u = plantation without hardwood ,
n = trees per acre ,
m = equivalent pine trees per acre ,

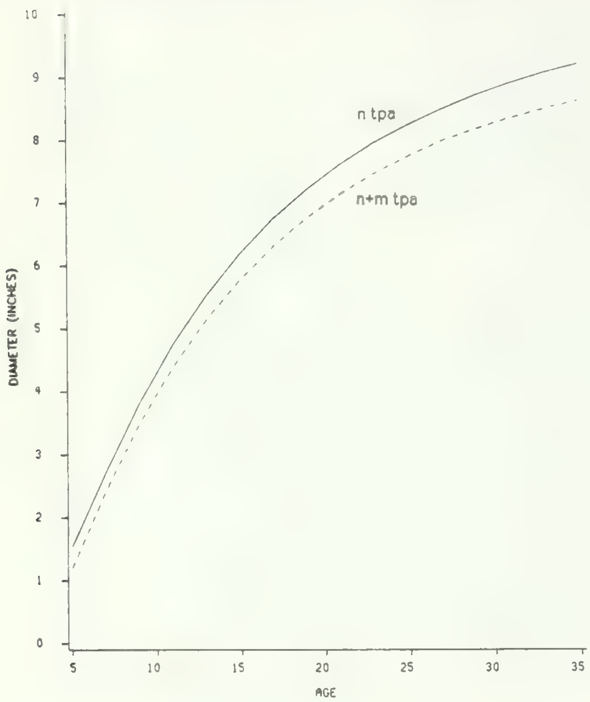
Again we assume $C_r$ to be equal to 1. Figure 2 presents the impact of this modified CCT on average stand diameter.

Now since the CCT method, and the model, is based on number of trees per acre we need a mechanism for determining m, given hardwood basal area. Basically, we are asking how many pine trees represent the same competitive effect of a certain quantity of hardwood. Remember, we have a hardwood model that projects basal area and we have a pine model based on trees per acre, and we have to come up with some procedure to relate the two. If we were to assume crown area per unit of basal area for the two species was equal we could divide the hardwood basal area by the average pine basal area and find the equivalent number of pine trees. However, given that competition for crown space is important we do not accept a one to one relationship between pine and hardwood basal area.

The approach we used to estimate the equivalence between pine and hardwood basal area was to compare the maximum basal areas predicted by the growth models. The assu ption is that at maximum basal area the site is fully occupied by

Figure 2.

DIAMETER RESPONSE TO HARDWOOD




the species, and since crown size is directly related to basal area the ratio of basal areas would give us the ratio of crown space occupied by a square foot of each species. Figure 3 is a plot of maximum basal area against pine site index for the three models. Using this relationship we then calculate the equivalent number of pine trees from the relationship

$$m = HBA/PBA/HADJ \quad , \qquad (3)$$

where HBA = hardwood basal area ,
PBA = average basal area per pine tree,
HADJ = the adjustment factor from the ratio of maximum hardwood basal area to maximum pine basal area.

Consider the following example. Suppose we had a plantation that had 595 trees per acre with an average diameter of 2.5 inches and a hardwood component representing 8 square feet of basal area. Further, assume that the hardwood to pine ratio for the site index of the stand is 0.77, then;

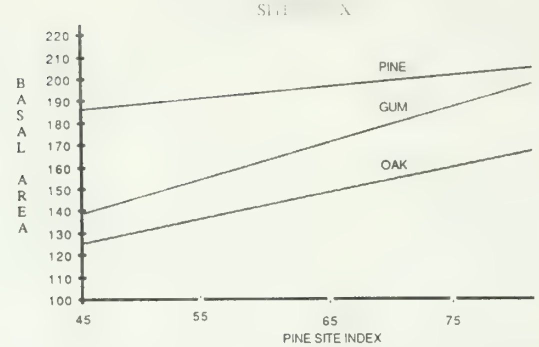
$$m = 8/(0.005454 * 2.5 * 2.5)/0.77 = 316,$$

and we would say that a pine stand of 595 trees per acre with 8 sq ft of hardwood will have an increment equivalent to a pure pine stand with 911 trees per acre.

This method is applied to the growth of the modal and minimum values of height and diameter used in the model. Growth of the maximum height and diameter are assumed to be uneffected by the hardwood. Figures 4, 5 and 6 graphically

Figure 3.

MAXIMUM BASAL AREA BY PINE




demonstrate the hardwood impact on the height and diameter characteristics. Since diameter growth is a function of height growth in the model, Figure 5 shows dominant height on the abscissa. In the model, dominant height is defined as the mean of the 100 tallest trees per acre. The impact of the height growth pattern on diameter is then presented in Figure 6. The reduction in the maximum diameter shown in Figure 6 is a result of the impact of the hardwood on the height distribution and the resulting reduction of dominant height over time. Finally, using this same method the mortality of the pine was developed. The mortality, $\Delta Y$, of the pine in a plantation containing hardwood is determined by apportioning the mortality, $\Delta X$, in an equivalent pine plantation to the pine. Figure 7 demonstrates the procedure. The relationship is:

Figure 4.

IMPACT OF HARDWOOD COMPETITION

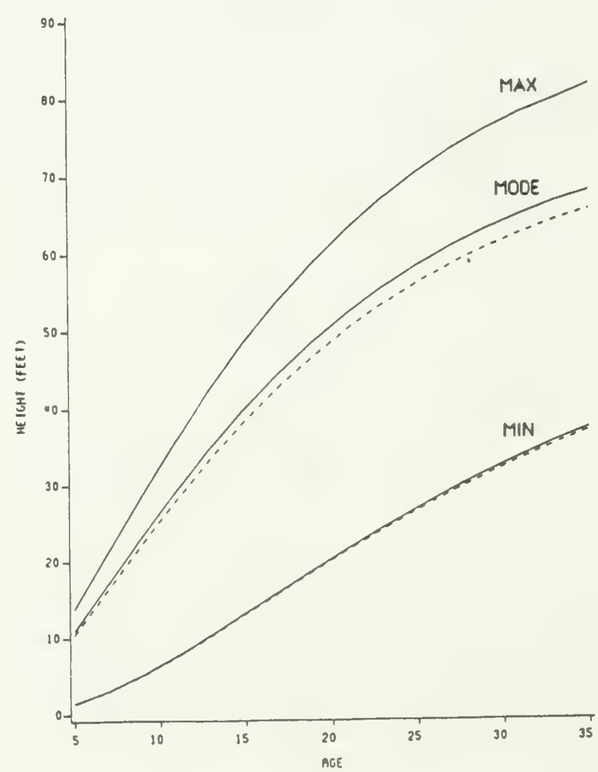


Figure 5.

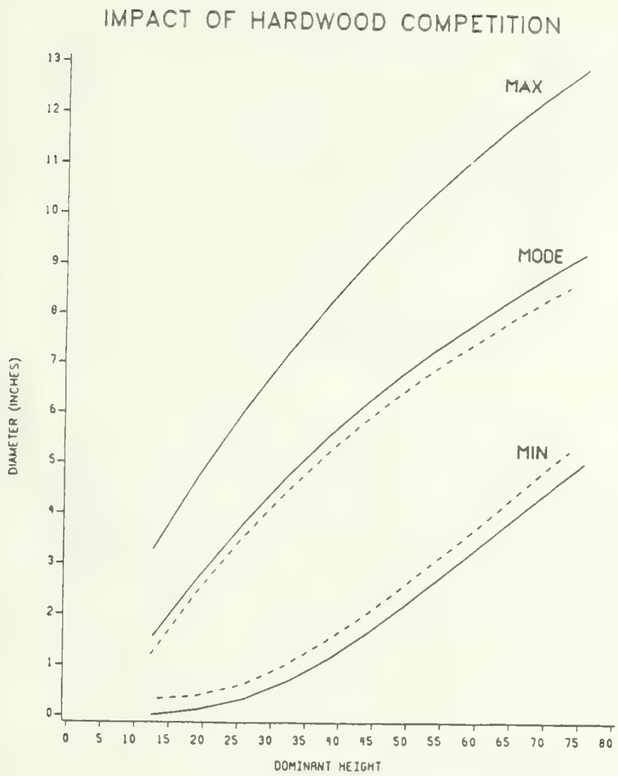



Figure 6.

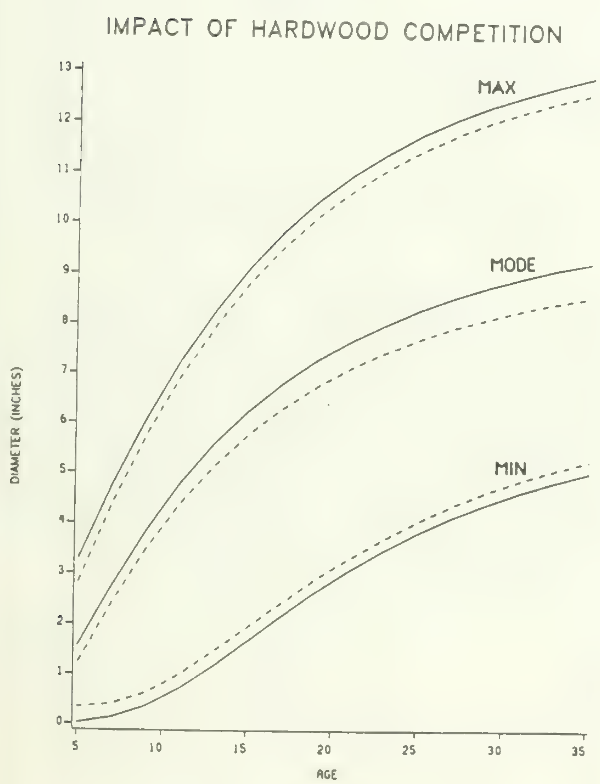
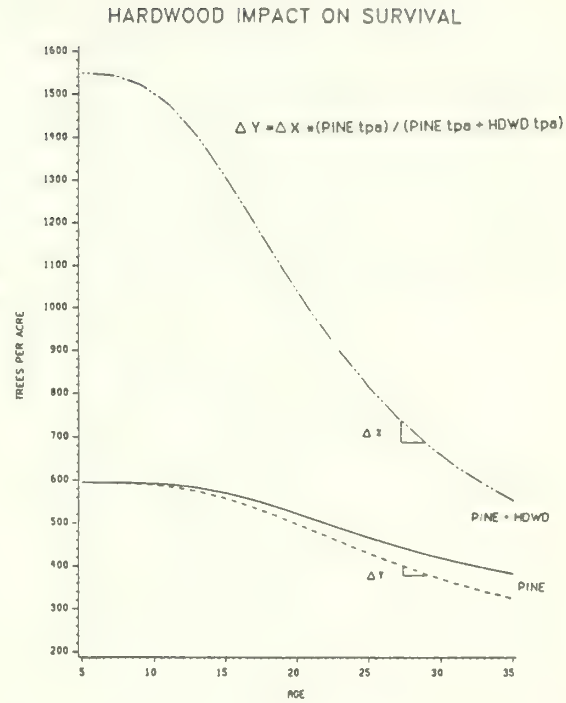



Figure 7.




$$\Delta Y = \Delta X * [\ n/(n + m)], \qquad (4)$$

where, n = number of pine trees per acre,
m = equivalent pine trees per acre as determined in equation 3.

## BIOLOGICAL OUTCOME

What then is the biological impact of these assumptions? Figure 8 demonstrates the performance of hardwood as a percent of total basal area over time based on its percent of total basal area at age 5. The initial vigor of the sprout growth contributes to the hardwood representing a large portion of the total basal area early in the life of the plantation. As the pine growth begins to accelerate the hardwood, as a percentage of the total basal, area declines. At about age 12 it becomes relatively flat and remains that way until about age 22. At that stage of development, mortality in the pine component results in a rapid decline in pine basal area growth, and hardwood basal area reaches the stage of rapid growth. As a result the percent hardwood in the stand begins to increase.

Figure 9 shows the relative total basal area for a pure stand of the decurrent hardwood species, a pure pine plantation, and a pine plantation with 40% of the total basal area in hardwood at age 5. The plantation was assumed to initially have 595 surviving stems per acre at establishment on a site index 65 feet (base age 25). The difference between the lines will differ with site index, but basically the pine plus hardwood will be less than the pure pine until we pass the age at which the pine basal area attains its maximum and begins to decline.

Figure 8.

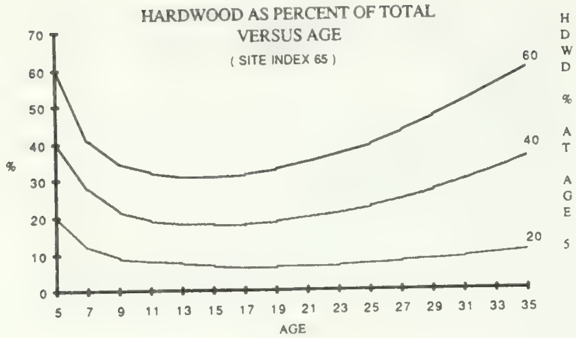
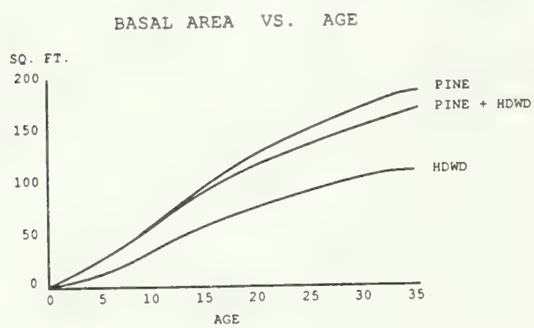
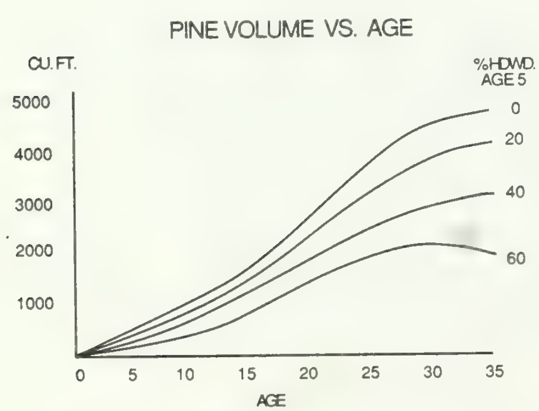



Figure 9.




The impact on volume is demonstrated in Figure 10. Again the original pine stand had 595 stems per acre at establishment on a site index 65 feet (base age 25). The figure shows the relative impact of increasing hardwood basal area as a percent of total basal area at age 5.

Figure 10.




We mentioned earlier that the impact of hardwood on the height distribution creates a reduction in dominant height, defined as the height of the tallest 100 trees, at index age 25. Figure 11 presents that impact for the pine plantation used in Figures 9 and 10. A hardwood basal area to 60% of total basal area at age 5 results in a 5 foot reduction in dominant height at index age 25.

Figure 11.

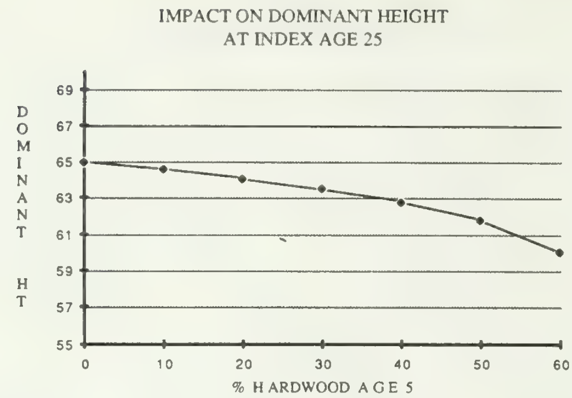
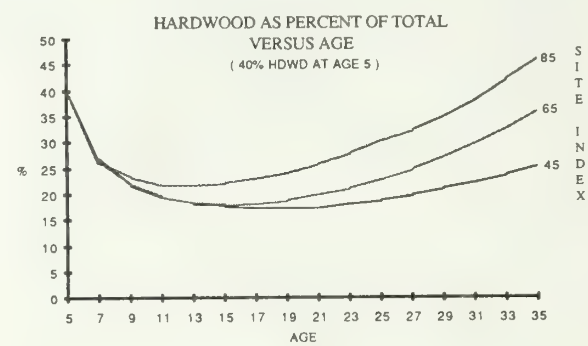



Figure 12 presents the impact of hardwood over time based on site index for the same example plantation with the hardwood at age 5 representing 40% of the total basal area. This demonstrates that on a poor site the competition from hardwood is less than on higher sites. On a pine site index 45 feet (base age 25) 40% hardwood at age 5 results in a 20% reduction in pine volume at age 35, while on a pine site index 85 there is a 40% reduction.

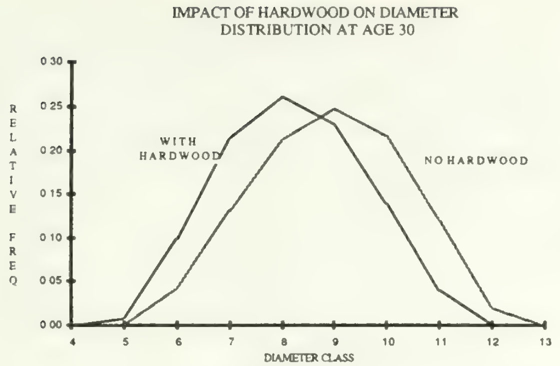
Figure 12.




Finally, Figure 13 presents the impact on the diameter distribution. Again the data are for the example plantation. The effect of hardwood is to create a more right skewed distribution of diameters. As shown in Figure 6 the maximum is reduced as a result of reduction in dominant height and, the mode and minimum values are reduced by the presence of hardwood basal area and its effect on dominant height. The data graphed in Figure 13 are class mid points. The actual values of the three characteristics at age 30 are:

| | No Hardwood (inches) | With Hardwood (inches) |
|---|---|---|
| Maximum | 12.6 | 12.2 |
| Mode | 9.0 | 8.3 |
| Minimum | 4.7 | 4.5 |

Figure 13.




## VERACITY

As indicated earlier there is very little long term data on which to test the outcome of our assumptions. One data set that was made available to us belongs to the Auburn University Silviculture Herbicide Cooperative and is located at Fayette, Alabama. The objective of the study was to evaluate different methods of mechanical and chemical site preparation. Percent hardwood was not recorded for earlier years but at age 12 ranged from 4 percent (3 sq ft) for a bulldozer and pile treatment to 76 percent (34 sq ft) for a hand injection treatment. We input the stand conditions of each plot at age 12 and predicted the stand conditions at the age 24 measurement. Table 1 presents a summary of the statistics comparing the observed and predicted values for the 21 plots.

Table 1. Summary statistics for comparison with 21 plots from the Fayette, AL study.

| Variable | Avg. * Diff. | Range | Mean Abs. Diff. | % Explained Variation |
|---|---|---|---|---|
| Trees/ac. | 14.6 | -119 to 74 | 27.6 | 89.0 |
| Ddh (in.) | 0.3 | - .4 to 1.6 | 0.49 | 81.1 |
| Pine BA (in.$^2$) | 7.8 | - 4 to 22 | 9.0 | 97.3 |
| Hdnd BA (in.$^2$) | - 7.1 | - 34 to 11 | 8.2 | 84.9 |

Difference = Observed - Predicted values at last measurement.

## ECONOMIC ANALYSIS

The quote at the beginning of the paper is from a paper titled "Folklore and Bromides in Forest Economics", Marquin, 1947. To test the often held assumption that all hardwood should be killed the product output from the model was input into QUICK-SILVER (Vasievich et al 1984). The yield for a stand with 40 percent hardwood with and without hardwood control at age 5 is presented in Tables 2 and 3, respectively, with the associated costs and revenues. Figure 14 presents the net present values after tax for treated and untreated stands having 10 to 60 percent hardwood at age 5. The results assume a 28 percent marginal rate for ordinary and capital gains income, a 10 percent tax credit, amortization of establishment costs, and expensing of treatment costs. The analysis assumes utilization of the hardwoods. Annual costs are not included. The stumpage values used were regional acreages and do not reflect other impacts of hardwood that may occur, such as increased logging cost.

Figure 14.

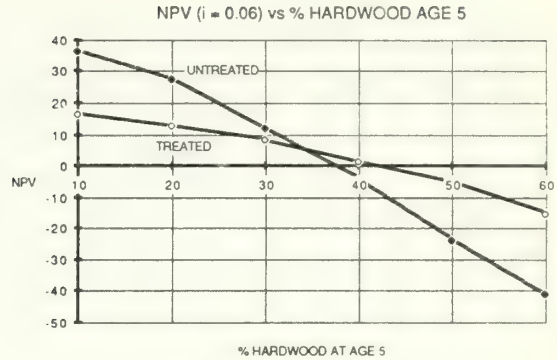



Table 2.

NORTH CAROLINA STATE UNIVERSITY PLANTATION MANAGEMENT SIMULATOR

Y I E L D T A B L E ( Loblolly Pine )

| SITE INDEX (BASE AGE 25) | PLANTING DENSITY (STEMS/ACRE) | PERCENT PLANTING SURVIVAL | INITIAL SURVIVAL (STEMS/ACRE) |
|---|---|---|---|
| 65 | 700 | 85 | 595 |

| AGE yrs | DOM HGT ft | TPA | AVE DIA in | AVE HGT ft | BASAL AREA PINE sq ft | BASAL AREA HDWD sq ft | TOTAL VOLUME cu ft(ib) | MAI | PAI |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 12 | 594 | 1.1 | 10 | 4 | 3 | 17 | 3 | 3 |
| 80 PERCENT OF THE HARDWOOD BASAL AREA HAS BEEN REMOVED | | | | | | | | | |
| 10 | 29 | 592 | 4.1 | 26 | 54 | 1 | 499 | 50 | 96 |
| 15 | 43 | 572 | 6.0 | 39 | 113 | 1 | 1574 | 105 | 215 |
| 20 | 55 | 526 | 7.2 | 50 | 161 | 1 | 2662 | 133 | 218 |
| 25 | 64 | 473 | 8.1 | 57 | 168 | 2 | 3428 | 137 | 153 |
| 30 | 70 | 426 | 8.6 | 63 | 173 | 2 | 3876 | 129 | 90 |

NOTE: HEIGHT/AGE CURVE FROM GOLDEN ET AL.
SOUTH. JOUR. APPL. FOR., 1981

HARDWOOD TYPE -- DECURRENT

FORESTRY INVESTMENT ANALYSIS — TRANSACTIONS

>>> QUICK-SILVER <<<
SOUTHEASTERN CENTER FOR FOREST ECONOMICS RESEARCH

FILE-HDWD40T Economics of Hardwood Management in Pine Plantations
PREPARED BY: W. D. Smith DATE 29 OCT 1986

Loblolly Pine Plantation SI(25) = 65
Site Prep by Chop and Burn - Plant 700 t/a
NO THINNING - 30 YEAR ROTATION
40 % Hardwood at age 5 - 80 % Controlled at age 5

| NO. | ACTIVITY / TAX CLASS | FIRST YEAR | LAST YEAR | STEP YEARS | CURRENT VALUE ($/UNIT) | RATE OF CHANGE (%/YR.) | QUANTITY | UNITS (PRODUCT) |
|---|---|---|---|---|---|---|---|---|
| 1 | SITE PREP / REFORESTATION COST | 0 | 0 | 0 | -65.00 | 0.00 | 1.00 | ACRES |
| 2 | PLANTING / REFORESTATION COST | 0 | 0 | 0 | -75.00 | 0.00 | 1.00 | ACRES |
| 3 | HERBICIDE / ORDINARY EXPENSE | 5 | 5 | 0 | -50.00 | 0.00 | 1 00 | ACRES |
| 4 | FINAL H'VEST / TIMBER SALE | 30 | 30 | 0 | 130.00 | 0.00 | 2.20 | MBF SAWTIMBER |
| 5 | FINAL H'VEST / TIMBER SALE | 30 | 30 | 0 | 36.50 | 0.00 | 14.00 | CUNITS CHIP-N-SAW |
| 6 | FINAL H'VEST / TIMBER SALE | 30 | 30 | 0 | 11.50 | 0.00 | 15.60 | CUNITS PULPWOOD |

SCHEDULE OF CASH FLOWS

| YEAR | ACTIVITY (PRODUCT) | QUANTITY | UNITS | COST AMOUNT ($) | REVENUE AMOUNT ($) | CUMULATIV TOTAL ($) |
|---|---|---|---|---|---|---|
| 0 | SITE PREP | 1.00 | ACRES | -65 00 | | -65 00 |
| 0 | PLANTING | 1.00 | ACRES | -75 00 | | -140 00 |
| 5 | HERBICIDE | 1.00 | ACRES | -50.00 | | -190 00 |
| 30 | FINAL H'VES (SAWTIMBER) | 2.20 | MBF | | 286 00 | 96 00 |
| 30 | FINAL H'VES (CHIP-N-SAW) | 14.00 | CUNITS | | 511 00 | 607 00 |
| 30 | FINAL H'VES (PULPWOOD) | 15.60 | CUNITS | | 179.40 | 786 40 |

AFTER TAXES

| DISCOUNT RATE (%) | 4 000 | 6.000 | 8.000 | 10 000 | 12 00 |
|---|---|---|---|---|---|
| PRESENT VALUE (COSTS) | -265 39 | -224.96 | -201 20 | -186 71 | -177 5 |
| PRESENT VALUE (BENEFITS) | 360.83 | 226.66 | 150 88 | 107 26 | 81 6 |
| PRESENT NET WORTH | 95 45 | 1 70 | -50 32 | -79 44 | -95 8 |
| BENEFIT/COST RATIO | 1.36 | 1 01 | 0 75 | 0 57 | 0 4 |
| ANNUAL EQUIVALENT VALUE | 5 52 | 0.12 | -4 47 | -8 43 | -11 9 |
| COMPOSITE RATE OF RETURN | 5.07 | 6 03 | 6 97 | 7 99 | 9.1 |
| INTERNAL RATE OF RETURN | 6 05 | 6 05 | 6 05 | 6.05 | 6 0 |

Table 3.

NORTH CAROLINA STATE UNIVERSITY PLANTATION MANAGEMENT SIMULATOR

Y I E L D   T A B L E ( Loblolly Pine )

| SITE INDEX (BASE AGE 25) | PLANTING DENSITY (STEMS/ACRE) | PERCENT PLANTING SURVIVAL | INITIAL SURVIVAL (STEMS/ACRE) |
|---|---|---|---|
| 66 | 700 | 85 | 595 |

| AGE yrs | DOM HGT ft | TPA | AVE DIA in | AVE HGT ft | BASAL AREA PINE sq ft | BASAL AREA HDWD sq ft | TOTAL VOLUME cu ft(ib) | MAI | PAI |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 12 | 594 | 1.1 | 10 | 4 | 3 | 17 | 3 | 3 |
| 10 | 29 | 588 | 4.0 | 25 | 51 | 10 | 467 | 46 | 88 |
| 15 | 43 | 567 | 5.8 | 38 | 102 | 15 | 1389 | 93 | 186 |
| 20 | 54 | 497 | 7.0 | 49 | 131 | 21 | 2274 | 114 | 177 |
| 25 | 63 | 429 | 7.7 | 56 | 140 | 26 | 2808 | 112 | 107 |
| 30 | 69 | 370 | 8.2 | 62 | 137 | 33 | 3020 | 101 | 42 |

NOTE HEIGHT/AGE CURVE FROM GOLDEN ET AL.
SOUTH. JOUR. APPL. FOR., 1981

HARDWOOD TYPE -- DECURRENT

FORESTRY INVESTMENT ANALYSIS
TRANSACTIONS

>>> QUICK-SILVER <<<
SOUTHEASTERN CENTER FOR
FOREST ECONOMICS RESEARCH

FILE-HDWD40U Economics of Hardwood Management in Pine Plantations
PREPARED BY W. D. Smith DATE 29 OCT 1986

Loblolly Pine Plantation SI(25) = 66
Site Prep by Chop and Burn - Plant 700 t/a
NO THINNING - 30 YEAR ROTATION
40 % Hardwood at age 5 - No Hardwood Control

| NO. | ACTIVITY / TAX CLASS | FIRST YEAR | LAST YEAR | STEP YEARS | CURRENT VALUE ($/UNIT) | RATE OF CHANGE (%/YR.) | QUANTITY | UNITS (PRODUCT) |
|---|---|---|---|---|---|---|---|---|
| 1 | SITE PREP / REFORESTATION COST | 0 | 0 | 0 | -65.00 | 0.00 | 1.00 | ACRES |
| 2 | PLANTING / REFORESTATION COST | 0 | 0 | 0 | -75.00 | 0.00 | 1.00 | ACRES |
| 3 | FINAL H'VEST / TIMBER SALE | 30 | 30 | 0 | 130.00 | 0.00 | 1.20 | MBF SAWTIMBER |
| 4 | FINAL H'VEST / TIMBER SALE | 30 | 30 | 0 | 36.50 | 0.00 | 10.30 | CUNITS CHIP-N-SAW |
| 5 | FINAL H'VEST / TIMBER SALE | 30 | 30 | 0 | 11.50 | 0.00 | 13.70 | CUNITS PULPWOOD |
| 6 | FINAL H'VEST / TIMBER SALE | 30 | 30 | 0 | 1.00 | 0.00 | 26.40 | TONS HARDWOOD |

SCHEDULE OF CASH FLOWS

| YEAR | ACTIVITY (PRODUCT) | QUANTITY | UNITS | COST AMOUNT ($) | REVENUE AMOUNT ($) | CUMULATIV TOTAL ($) |
|---|---|---|---|---|---|---|
| 0 | SITE PREP | 1.00 | ACRES | -65.00 | | -65 00 |
| 0 | PLANTING | 1.00 | ACRES | -75.00 | | -140.00 |
| 30 | FINAL H'VES (SAWTIMBER) | 1.20 | MBF | | 156.00 | 16 00 |
| 30 | FINAL H'VES (CHIP-N-SAW) | 10.30 | CUNITS | | 375.95 | 391 95 |
| 30 | FINAL H'VES (PULPWOOD) | 13.70 | CUNITS | | 157.55 | 549 50 |
| 30 | FINAL H'VES (HARDWOOD) | 26.40 | TONS | | 26.40 | 575 90 |

AFTER TAXES

| DISCOUNT RATE (%) | 4.000 | 6 000 | 8 000 | 10.000 | 12.00 |
|---|---|---|---|---|---|
| PRESENT VALUE (COSTS) | -201 80 | -174 90 | -159 92 | -151 49 | -146 6 |
| PRESENT VALUE (BENEFITS) | 269 01 | 170.84 | 115.47 | 83 65 | 64 9 |
| PRESENT NET WORTH | 67.21 | -4 06 | -44 45 | -67 83 | -81 7 |
| BENEFIT/COST RATIO | 1 33 | 0 98 | 0 72 | 0 55 | 0.4 |
| ANNUAL EQUIVALENT VALUE | 3 89 | -0.29 | -3 95 | -7.20 | -10 1 |
| COMPOSITE RATE OF RETURN | 5.00 | 5.92 | 6.[illegible] | 7.84 | 9 0 |
| INTERNAL RATE OF RETURN | 5 85 | 5 85 | 5 85 | 5 85 | 5 8 |

## SUMMARY

We have presented a rationale for evaluating the impact of hardwood competition in pine plantations along with the implications of that rationale. Without further, more detailed, data the best evaluation of these results is that they reflect the biology of the situation as we understand it.

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## Seedling Production

Moderator:

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North Carolina State University

# THE INFLUENCE OF SEEDBED DENSITY ON LOBLOLLY AND SLASH PINE SEEDLING GRADE DISTRIBUTIONS[1/]

James N. Boyer and David B. South[2/]

Abstract.--Since the 1930's, several investigators have studied the effect of seedbed density on loblolly and slash pine seedling morphology. The purpose of this paper was to compare the data from these studies and to show the general relationship between seedbed density and the distribution of seedling grades. Seedlings were classified into three grades (grade 1, grade 2, and cull) based solely on root-collar diameter. For each study, models were developed to predict the proportion of seedling grades for a given density. These models varied depending upon the particular study, nursery, or species. It is hypothesized that biological and cultural conditions such as fertility, undercutting, irrigation, date of sowing and date of lifting influence these curves.

Keywords: Root-collar diameter, seedling morphology.

## INTRODUCTION

Morphological grades for loblolly (Pinus taeda L.) and slash (Pinus elliottii var elliottii Engelm.) seedlings suggested by Wakeley (1954) were based upon root-collar diameter, among other factors. A grade 1 seedling must be 4.8 millimeters or greater, and a grade 2 seedling is 3.2 millimeters or greater. Seedlings with a diameter less than 3.2 millimeters (grade 3 seedlings) are considered culls.

Several studies have shown that grade 1 seedlings can show increased growth over lower grade seedlings (South and Mexal 1984), yet southern forest nurseries produce very few grade 1 seedlings (South et al. 1985). A recent survey of 53 southern forest nurseries revealed that most loblolly pine seedlings produced today are grade 2 or less (Boyer and South 1986). Half of the nurseries surveyed produced 4 percent grade 1 or less. Marx et al. (1984) reported many nurseries producing more than 10 percent culls. Final seedbed density for loblolly and slash pine exceeded 300 per square meter in 80 percent of the studies.

Operational grading of southern pine seedlings is not currently done at any forest nursery, although some nurseries do cull small, deformed or diseased trees. However, several research studies have demonstrated how seedbed density affects the distribution of seedling grades (Burns and Brendemuehl 1971; Shoulders 1961; Negben and Meyer 1986). Harms and Langdon (1977) and May (1933) described the effect of density on overall seedling morphology. Other data on these effects remain unpublished.

The objective of this paper was to bring together data from these published and unpublished studies and create models which show how the distributions of loblolly and slash pine seedlings in each grade change with changing seedbed density. The authors attempt to explain some of the possible reasons why the grade distributions for any one density may vary at different nurseries.

## DATA SOURCES AND MODELS

Data from 16 studies showing the relationship between seedbed density and the proportion of loblolly or slash pine seedlings in each grade (1, 2, and cull) based on root-collar diameter were obtained from 10 different sources in 9 states from Virginia to Texas (Table 1). These sources included two unpublished studies installed by the Auburn University Southern Forest Nursery Management Cooperative at one nursery in Alabama; data taken directly from two publications reporting the results of density studies in Florida and Louisiana (Burns and Brendemuehl 1971; Shoulders 1961); additional data provided by the authors of three published density studies in South

[1/]Presented at the Fourth Biennial Southern Silvicultural Research Conference in Atlanta, Georgia, November 4-6, 1986.

[2/]Research Associate and Assistant Professor, Auburn University Southern Forest Nursery Management Cooperative, School of Forestry, Auburn University, AL 36849-4201.

Table 1. Available information on the density studies.

| State | Species | No. Years | Yr. of Study | Sow Date | Date Thinned | Lift Date | N | Density Classes | Density Range |
|---|---|---|---|---|---|---|---|---|---|
| AL - '83 | Loblolly | 1 | 1983 | May 10 | --- | Dec. 15 | 45 | 5 | 32-312[A] |
| AL - '85 | Loblolly | 1 | 1985 | April 27 | --- | Jan. 15 | 30 | 6 | 92-563[A] |
| AR | Loblolly | 1 | 1979 | ? | --- | ? | 6 | 3 | 161-484[B] |
| FL | Loblolly | 1 | 1984 | April 6 | May | Jan. | 15 | 5 | 215-431[C] |
| FL | Slash | 2 | 1958-59 | ? | --- | ? | 8 | 5 | 99-574[A] |
| GA | Loblolly | 1 | 1984 | Mid-April | --- | Dec. 6 | 10 | 6 | 105-627[A] |
| GA | Slash | 1 | 1984 | Mid-April | --- | Dec. 6 | 10 | 6 | 124-614[A] |
| LA | Loblolly | 4 | ? | ? | ? | ? | 12 | 4 | 127-526[D] |
| LA | Slash | 4 | ? | ? | ? | ? | 16 | 4 | 116-483[D] |
| MS - F1 | Loblolly | 3 | 1957-59 | April 22-24 | Late May | 1/30-2/25 | 36 | 4 | 161-646[C] |
| MS - F2 | Loblolly | 3 | 1957-59 | April 22-24 | Late May | 1/30-2/25 | 36 | 4 | 161-646[C] |
| MS - F3 | Loblolly | 3 | 1957-59 | April 22-24 | Late May | 1/30-2/25 | 36 | 4 | 161-646[C] |
| SC | Loblolly | 1 | 1977 | Mid-April | Early July | Feb. | 60 | 12 | 86-721[C] |
| TX - U1 | Loblolly | 3 | 1982-84 | Early April | July | Dec.-Jan. | 18 | 3 | 258-431[C] |
| TX - U2 | Loblolly | 3 | 1982-84 | Early April | July | Dec.-Jan. | 18 | 3 | 258-431[C] |
| VA | Loblolly | 1 | 1982 | ? | --- | Oct. 20-21 | 60 | 60 | 280-732[E] |

F1 = 84,25,70 kg/ha N-P-K
F2 = 168,50,140 kg/ha N-P-K
F3 = 335,100,280 kg/ha N-P-K
U1 = No undercutting
U2 = Undercut in July, Sept.

[A] Sown at different densities; actual plot densities used.
[B] Sown at different densities; sowing density classes used.
[C] Thinned; target density classes used.
[D] Thinned; actual densities used.
[E] Operational range of densities.

Carolina, Mississippi and Texas (Harms and Langdon 1977; Switzer and Nelson 1963; Nebgen and Meyer 1986); three unpublished studies from Arkansas, Florida and Georgia; and data from operational beds at a nursery in Virginia where there was a wide range of seedbed densities. In some instances, more than one species was tested or a second treatment such as fertilizer was included. In these cases, each set of data was taken separately. The information obtained from these studies was in varying degrees of completeness. Some were studies in which seeds were sown at different densities, while others were sown at a single density and thinned to different densities at various times after sowing (Table 1). Some data included the actual seedbed densities at time of lifting and measurement, while others reported only the target or sowing densities (Table 1).

Curvilinear regressions were computed for each grade in each study, regressing the percent in a given grade on the seedbed density (Tables 2, 3, and 4; Figure 1). Where possible, individual plot values were used in these regressions. Otherwise, the overall mean for each density reported was used. All curves for grade 1 were fitted to an exponential model of the form $e^{-X}$, while grade 2 and cull models were of the quadratic form. In general, models predicting either the percentage of grade 1 and cull seedlings had higher R-square values than models predicting the percentage of grade 2 seedlings.

Table 2. Computed coefficients and R-square values for nonlinear regressions of grade 1 percent (Y) on density (X = number per square meter). Model: $Y = B_0 * e^{(-B_1 * X)}$.

| State | Species | $B_0$ | $B_1$ | $R^2$ |
|---|---|---|---|---|
| AL - '83 | Loblolly | 97.0 | 0.00864 | 0.75 |
| AL - '85 | Loblolly | 134.6 | 0.00348 | 0.92 |
| AR | Loblolly | 154.8 | 0.00544 | 0.95 |
| FL | Loblolly | 324.9 | 0.01004 | 0.92 |
| FL | Slash | 121.4 | 0.00425 | 0.97 |
| GA | Loblolly | 117.9 | 0.00897 | 0.95 |
| GA | Slash | 72.6 | 0.00960 | 0.98 |
| LA | Loblolly | 147.1 | 0.00348 | 0.89 |
| LA | Slash | 117.7 | 0.00254 | 0.70 |
| MS - F1 | Loblolly | 119.2 | 0.00389 | 0.36 |
| MS - F2 | Loblolly | 132.1 | 0.00374 | 0.67 |
| MS - F3 | Loblolly | 87.7 | 0.00092 | 0.20 |
| SC | Loblolly | 126.9 | 0.00295 | 0.87 |
| TX - U1 | Loblolly | 161.4 | 0.00482 | 0.39 |
| TX - U2 | Loblolly | 459.5 | 0.01088 | 0.42 |
| VA | Loblolly | 91.3 | 0.00277 | 0.22 |

Table 3. Computed coefficients and R-square values for nonlinear regressions of grade 2 percent (Y) on density (X = number per square meter). Model: $Y = B_0 + (B_1 * X) + (B_2 * X^2)$.

| State | Species | $B_0$ | $B_1$ | $B_2$ | $R^2$ |
|---|---|---|---|---|---|
| AL - '83 | Loblolly | 10.25 | 0.537 | -0.001145 | 0.66 |
| AL - '85 | Loblolly | -20.77 | 0.284 | -0.000272 | 0.89 |
| AR | Loblolly | - 9.50 | 0.329 | -0.000470 | 0.65 |
| FL | Loblolly | -67.98 | 0.871 | -0.001249 | 0.94 |
| FL | Slash | -17.98 | 0.374 | -0.000415 | 0.91 |
| GA | Loblolly | 50.63 | 0.041 | -0.000117 | 0.36 |
| GA | Slash | 77.65 | -0.097 | -0.000018 | 0.91 |
| LA | Loblolly | -28.79 | 0.288 | -0.000309 | 0.82 |
| LA | Slash | - 0.29 | 0.106 | -0.000042 | 0.55 |
| MS - F1 | Loblolly | -18.79 | 0.376 | -0.000434 | 0.23 |
| MS - F2 | Loblolly | -22.82 | 0.360 | -0.000321 | 0.64 |
| MS - F3 | Loblolly | 8.81 | 0.108 | -0.000080 | 0.14 |
| SC | Loblolly | - 5.65 | 0.169 | -0.000165 | 0.49 |
| TX - U1 | Loblolly | 54.17 | -0.104 | 0.000360 | 0.39 |
| TX - U2 | Loblolly | -143.50 | 1.273 | -0.001764 | 0.23 |
| VA | Loblolly | 50.50 | 0.030 | -0.000001 | 0.05 |

Table 4. Computed coefficients and R-square values for nonlinear regressions of cull percent (Y) on density (X = number per square meter). Model: $Y = B_0 + (B_1 * X) + (B_2 * X^2)$.

| State | Species | $B_0$ | $B_1$ | $B_2$ | $R^2$ |
|---|---|---|---|---|---|
| AL - '83 | Loblolly | 1.50 | 0.0229 | 0.000149 | 0.53 |
| AL - '85 | Loblolly | -0.98 | 0.0155 | 0.000080 | 0.95 |
| AR | Loblolly | -30.00 | 0.2338 | -0.000163 | 0.97 |
| FL | Loblolly | 18.15 | -0.1543 | 0.000362 | 0.90 |
| FL | Slash | 4.09 | 0.0097 | 0.000039 | 0.91 |
| GA | Loblolly | -22.93 | 0.2655 | -0.000197 | 0.89 |
| GA | Slash | -15.11 | 0.2532 | -0.000139 | 0.96 |
| LA | Loblolly | 3.85 | -0.0104 | 0.000166 | 0.84 |
| LA | Slash | 5.00 | -0.0216 | 0.000162 | 0.86 |
| MS - F1 | Loblolly | 2.67 | 0.0018 | 0.000083 | 0.23 |
| MS - F2 | Loblolly | 8.30 | -0.0603 | 0.000102 | 0.34 |
| MS - F3 | Loblolly | 3.03 | -0.0259 | 0.000048 | 0.20 |
| SC | Loblolly | -17.10 | 0.1364 | -0.000066 | 0.74 |
| TX - U1 | Loblolly | 33.50 | -0.1955 | 0.000315 | 0.16 |
| TX - U2 | Loblolly | 34.83 | -0.2255 | 0.000416 | 0.24 |
| VA | Loblolly | -9.77 | 0.0417 | -0.000002 | 0.30 |

## RESULTS AND DISCUSSION

Several of the density studies were thinned to the desired densities, rather than sown at different densities. Two studies were thinned as late as July. By this time, there may already have been competition or shading effects, which could influence response to lowered densities.

In every study, increasing seedbed density led to a reduction in the proportion of grade 1 seedlings and an increase in the cull percent. At the lower densities, the proportion of grade 2 seedlings tended to increase with density, but generally levelled off or decreased in the higher density ranges.

Many organizations manage for a seedbed density of 300 seedlings per square meter. Table 5 shows that the seedlings produced at this density can vary widely in terms of their grade distributions. This variation may be explained by a number of factors which will be discussed later. While four of the 16 studies had greater than 50 percent grade 1 seedlings at this density (300 per square meter), five others had less than 20 percent grade 1. Table 5 also lists the density required to produce 300 plantable seedlings per square meter. While all or nearly all the seedlings were plantable at this density for several studies, it was impossible to get 300 plantables at any density for three others. These results demonstrate that sowing at the same density will not produce the same results at every nursery and in every situation.

Table 5. Predicted values for grade distributions at 300 and 200 seedlings per square meter, and density required to produce 300 and 200 plantable seedlings per square meter.

| | | Predicted Grades at 300/$m^2$ | | | Density Required to produce 300 | Predicted Grades at 200/$m^2$ | | | Density Required to produce 200 |
|---|---|---|---|---|---|---|---|---|---|
| State | Species | Grade 1 | Grade 2 | Cull | Plantables/$m^2$ | Grade 1 | Grade 2 | Cull | Plantables/$m^2$ |
| | | ------ pct ------ | | | (#/$m^2$) | ------ pct ------ | | | (#/$m^2$) |
| AL - 83 | Loblolly | 7 | 68 | 22 | 503[A] | 17 | 72 | 12 | 237 |
| AL - 85 | Loblolly | 47 | 40 | 11 | 356 | 67 | 25 | 5 | 212 |
| AR | Loblolly | 30 | 47 | 26 | ---[B] | 52 | 38 | 10 | 246 |
| FL | Loblolly | 16 | 81 | 4 | 318 | 44[A] | 56[A] | 2[A] | 205[A] |
| FL | Slash | 34 | 57 | 10 | 341 | 52 | 40 | 8 | 216 |
| GA | Loblolly | 8 | 52 | 39 | ---[B] | 20 | 54 | 22 | 418 |
| GA | Slash | 4 | 47 | 48 | ---[B] | 11 | 57 | 30 | ---[C] |
| LA | Loblolly | 52 | 30 | 16 | 448 | 73 | 16 | 8 | 217 |
| LA | Slash | 55 | 28 | 13 | 377 | 71 | 19 | 7 | 214 |
| MS - F1 | Loblolly | 37 | 55 | 11 | 342 | 55 | 39 | 6 | 211 |
| MS - F2 | Loblolly | 43 | 56 | 0 | 300 | 62 | 36 | 0 | 200 |
| MS - F3 | Loblolly | 67 | 34 | 0 | 300 | 73 | 27 | 0 | 200 |
| SC | Loblolly | 52 | 30 | 18 | 418 | 70 | 21 | 8 | 228 |
| TX - U1 | Loblolly | 38 | 55 | 3 | 309 | 62[A] | 48[A] | 7[A] | 216[A] |
| TX - U2 | Loblolly | 18 | 80 | 5 | 315 | 52[A] | 40[A] | 6[A] | 217[A] |
| VA | Loblolly | 40 | 59 | 3 | 310 | 52[A] | 56[A] | 0[A] | 200[A] |
| Average | | 34 | 51 | 14 | | 52 | 40 | 8 | |

[A] Outside the range studied.
[B] Impossible to produce 300 plantables/$m^2$.
[C] Impossible to produce 200 plantables/$m^2$.

## Length of Growing Season

On average, reducing seedbed density will increase the percentage of grade 1 seedlings while decreasing the production of culls. For these studies, when the density is reduced from 300 to 200 per square meter, the percent of grade 1 seedlings is increased by an average of 18 percentage points and the cull percent is reduced from an average of 14 percent to 8 percent (Table 5). When using expensive seed, reducing the cull percent can result in dramatic savings in seed costs (South 1986). Furthermore, increasing the percentage of grade 1 seedlings can increase future wood production (Caulfield et al. 1987).

While each study showed nearly the same type of response to density, the magnitude of the response was highly variable between studies. In some studies, the percentage of grade 1 seedlings dropped rapidly when density was raised above the very lowest levels, with culls increasing correspondingly. In other studies, the response was not as dramatic, and the distributions were less sensitive to density. Seed source or family may affect response to density. Various cultural practices such as timing of sowing and lifting, fertility and soil management, undercutting, and irrigation can also affect diameter distributions at different densities.

The effects of sowing and lifting timing were demonstrated by the two Alabama studies conducted at the same nursery in two different years. The first year, seedlings were sown in May and lifted in mid-December (Table 1), and the percentage of grade 1 seedlings dropped rapidly as seedbed densities were increased above 100 per square meter. The second year, seedlings were sown in April and measured in mid-January. In this study, the proportion of grade 1 seedlings remained much higher at greater densities. Perry (1971) showed that loblolly pine seedlings increased significantly in weight from December to January and from January to February. McNabb (1985) demonstrated that slash pine seedlings can increase in diameter through the fall and winter. Furthermore, delaying sowing can result in a reduction in seedling diameter at the end of the season. Sowing just a week or two earlier in the spring can have a significant effect on seedling size by the end of the year because of the exponential nature of seedling growth (van den Driessche 1969).

## Fertility

Data from the Virginia nursery seem to contradict the importance of lifting or measurement timing. These seedlings were measured in October, yet show a relatively large proportion of grade 1 seedlings. This may be explained by fertility. This nursery is usually fertilized with a high rate of nitrogen (240 kg/ha), which is about 50 percnt greater than most nurseries apply and may compensate somewhat for the reduced growing space and increased competition at higher densities. The fertility effect is demonstrated clearly by the Mississippi data. Seedlings grown at higher densities respond proportionately more to nitrogen fertilization than seedlings grown at lower densities (Fisher and Mexal 1984). With the highest rate of fertilizer, increasing density from 161 to 300 per square meter had a marginal effect on the proportion of seedling grades. Pharis et al. (1964) also showed that diameter growth is markedly affected by the level of nitrogen supplied.

## Undercutting

The effect of undercutting on the distribution of seedling grades was demonstrated by the Texas studies. Seedlings which were undercut had fewer grade 1 seedlings. Undercutting and wrenching have been found to reduce root-collar diameter in loblolly (Miller et al. 1985; Tanaka et al. 1976; Walstad et al. 1977) and radiata pine (*Pinus radiata* D. Don) seedlings (Rook 1971).

## Irrigation

Irrigation is another factor which can influence these curves. Unpublished data from the Auburn University Southern Forest Nursery Cooperative have shown that at a sandy nursery in Florida, irrigating in the fall can significantly increase root-collar diameter (by about 10 percent). Minko (1975) increased seedling diameter by 20 percent or more by increasing irrigation by 12.7 mm per week in the early part of the growing season.

## SUMMARY AND CONCLUSIONS

These studies, conducted at several different nurseries across the South, show that seedling grade distribution responds to seedbed density in a similar manner. That is, the proportion of grade 1 seedlings drops relatively sharply as density is increased, then levels off near zero. The grade 1 curve is typically in the $e^{-X}$ form. The cull percent generally rises gradually with increasing density until the higher densities when it rises more sharply. The percent of grade 2 seedlings usually increases through the lower densities, then levels off or decreases as culls begin to make up the greatest proportion of the seedling population at the higher densities.

The magnitude of these responses can be greatly affected by cultural practices such as fertilization, irrigation, and undercutting. Increased nitrogen fertilization and irrigation can to some extent offset the competitive effects of higher densities, while undercutting may reduce seedling diameter and thus decrease the proportion of seedlings in the higher grades. Waiting until the seedlings have become established and are interacting with each other to thin to desired densities may not have the same effect as sowing at lower densities.

While many seedbed density studies have been conducted in southern nurseries, the investigators rarely report cultural practices such as sowing and lifting dates, soil type, fertilization and irrigation regimes, and other cultural practices which are likely to affect how seedling morphology responds to changing seedbed density. The intent of this paper was to not only demonstrate how seedling grade responds to seedbed density but also to show that the actual distribution of grades at any one density will depend upon many factors. Our attempts to explain differences and similarities among these studies were hampered by a lack of information on how the seedlings were raised. More complete information on seedling culture in studies like this would be desirable so that research efforts may be more definitively compared.

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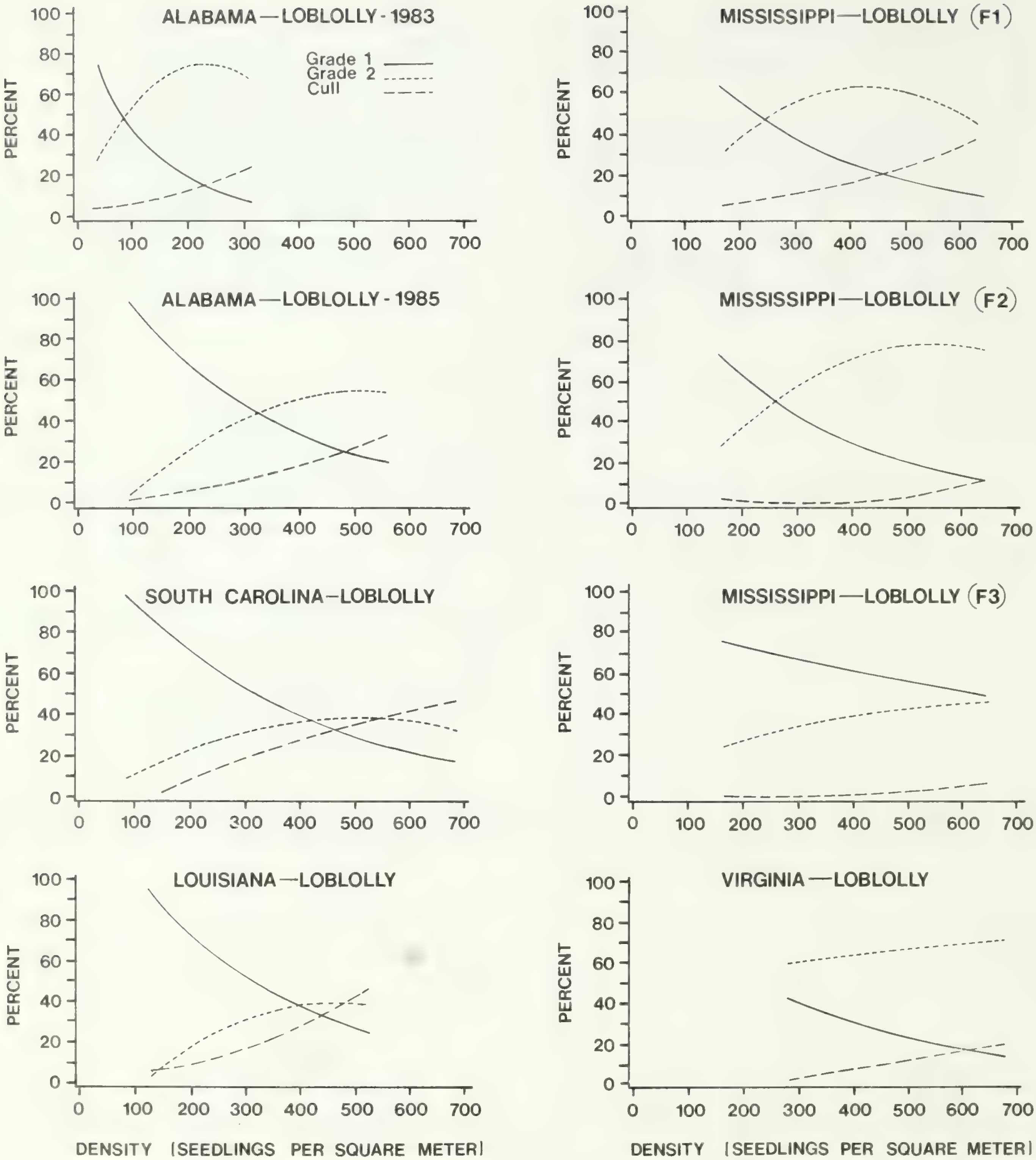


Figure 1.--Curvilinear regressions of percent in each grade on seedbed density for each study.

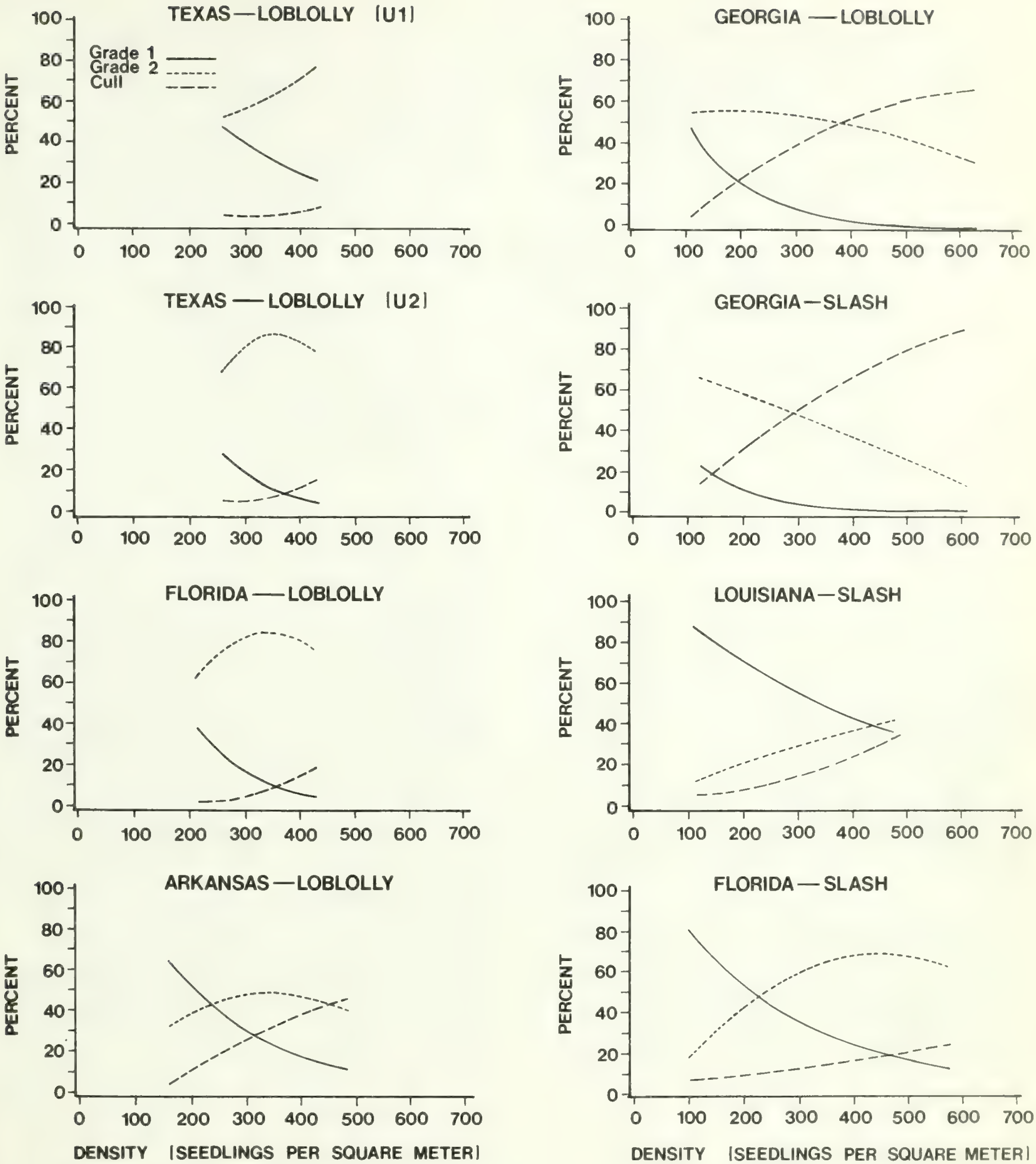


Figure 1.--Continued.

# EFFECTS OF NURSERY BED DENSITY AND FERTILIZATION ON THE MORPHOLOGY, NUTRIENT STATUS, AND ROOT GROWTH POTENTIAL OF SHORTLEAF PINE SEEDLINGS[1]

John C. Brissette and William C. Carlson[2]

Abstract.--The effects of seedbed density and different levels of phosphorus nitrogen on the morphology and physiology of shortleaf pine seedlings were studied under operational nursery conditions. Density and the amount of nitrogen applied affected diameter, height, and root volume, but the level of phosphorus in the soil did not. Based on these morphological measures that were obtained from 40 treatment combinations, 9 treatments (3 levels of density and 3 levels of nitrogen) were selected for physiological evaluation. Among the selected treatments, nutrient concentrations were affected most by nitrogen application. Although the combined concentration of nitrogen in stems and needles was dependent on total nitrogen applied, the relationship was not linear. Phosphorus and potassium concentrations both declined with increasing total nitrogen. At 15° and 20°C, root growth potential was related to density, root volume, and nitrogen application. The number of new roots increased with decreasing density and increasing root volume. Though applied nitrogen had an affect on root growth potential, the relationship was not clearly defined.

## INTRODUCTION

Shortleaf pine (Pinus echinata Mill.) is the most important species used for artificial regeneration on the Ouachita and Ozark National Forests. Approximately 12 million seedlings are planted annually on about 17,000 acres of the two forests. The success of the program has been limited by poorer survival and slower initial growth than are generally obtained with the southern pines on other national forests throughout the Southern Region. Poor seedling performance may be related to: (1) the generally droughty soil conditions on many sites, (2) poor seedling handling and planting techniques, or (3) the quality of the seedlings produced for planting on these mountain sites.

Seedling quality can be defined both in terms of morphology and physiology. The most widely recognized standards of morphological quality for southern pine planting stock are those described by Wakeley (1954), which specify that undamaged, disease-free shortleaf pine seedlings have a root collar diameter greater than 3.2 mm to be considered plantable. Recognizing the effect of the basal crook in shortleaf pine, Chapman (1948) recommended a minimum diameter of 2.5 mm at 2.5 cm above the ground line. In general, such morphological criteria for culling seedlings are substantiated by outplanting success. However, there are enough exceptions that Wakeley (1949) recommended the development and adoption of physiological grades that better reflect survival and growth potential. He suggested measuring such physiological attributes as nutrient content, stored food reserves, and seedling water status. Since then, much progress has been made in the physiological evaluations of planting stock, with root growth potential (RGP) receiving most the attention (Stone 1955, Stone and Jenkinson 1971, Burdett 1979a, Ritchie 1985). RGP is a measure of a seedling's readiness to produce new roots; relatively higher RGP indicates better seedling quality than lower RGP.

Shortleaf pine has not received much attention by nursery researchers in the past. At most nurseries where it is grown, shortleaf pine is cultured much like loblolly pine (P. taeda L.). However, in an early study, Huberman (1940) showed that shortleaf pine has a different growth pattern than loblolly pine. Therefore, it is possible that altering nursery culture for shortleaf pine would improve seedling quality and field performance. Two basic aspects of bare-root seedling culture that greatly influence stock quality are soil fertility and seedbed density (Switzer and Nelson 1963).

The purpose of this study was to determine the effects of seedbed density and different levels of phosphorus and nitrogen on the

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morphology and physiology of shortleaf pine seedlings growing in a nursery.

MATERIALS AND METHODS

Nursery Design and Treatments

Seedlings for this study were grown at Weyerhaeuser Company's Magnolia Forest Regeneration Center in Columbia County, Arkansas. The nursery soil is classified as Ruston fine sandy loam. The study was laid out on eight beds, seven between two adjacent irrigation lines plus an adjoining bed. Because phosphorus (P) must be incorporated before the seedbeds are formed, and to conserve space, a split-split plot design was used. The major plots were two levels of P fertility on a 60-m segment of a nursery bed. The subplots were five levels of seedbed density, and the sub-sub plots were four levels of nitrogen (N) fertilizer applied during the growing season as topdressings. The density subplots were 12 m long and each N sub-subplot was 3 m. The study contained 40 treatment combinations replicated 4 times for a total of 160 plots.

The two levels of P were: (1) the base level in the soil when sampled in December 1984 (approximately 54 p/m by the Strong Bray extraction method) and (2) enough added fertilizer to theoretically yield 150 percent of level 1 (approximately 81 p/m). For level 2, 300 kg/ha of 0-46-0 fertilizer was incorporated in two equal applications 1 and 2 weeks before sowing.

Seeds for the study were from the medium-size fraction of a bulked seed lot collected at the USDA Forest Service's Ouachita-Ozark Seed Orchard near Mt. Ida, Arkansas. The seeds were sown with a Weyerhaeuser-designed precision vacuum sower on April 16, 1985. The five target densities of living seedlings were: (1) $160/m^2$, (2) $230/m^2$, (3) $295/m^2$, (4) $360/m^2$, and (5) $430/m^2$.

Topdressing with N began on May 28, 1985, 6 weeks after sowing. Ammonium sulphate (21 percent N and 23 percent sulfur) was applied with a Gandy® fertilizer spreader calibrated to apply 11 and 17 kg N/ha. It was pulled over each bed two times and was opened or closed over each plot, on one or both passes, to apply the specified rate of fertilizer. Application dates after May 28 were June 13, June 25, July 11, and July 26. Total N applied for the four levels was: (1) 55 kg/ha, (2) 85 kg/ha, (3) 110 kg/ha, and (4) 170 kg/ha. All other nursery cultural practices were operational, based on the nursery manager's best judgement. On August 21, the seedlings were undercut (horizontally root pruned) at 15 cm to help control shoot growth. The actual density of each plot was determined on September 6. They were undercut again on November 21.

Actual seedbed densities in this study were lower than the target densities because germination was poorer than expected. Average density for each level in the study was: $141/m^2$, $218/m^2$, $269/m^2$, $296/m^2$, and $296/m^2$. Note that the two highest levels were the same. Although the highest density was well below the sowing target, it was higher than the operational level ($270/m^2$) recommended by Chapman (1948) but much lower than the density ($540-590/m^2$) suggested as a maximum by Wakeley (1954).

Seedling Measurements and Analyses

On December 10, 1985, an eight-seedling transect, representing one seedling from each drill row, was carefully hand-lifted from within the center 2 m of each plot. These seedlings were measured for diameter, height, and root volume. Root volume was determined by the displacement method (Burdett 1979b). The effects of the nursery treatments on each seedling attribute were evaluated separately using analysis of variance. For factors with significant differences, orthogonal polynomial comparisons were made to evaluate the effects of the levels within that factor (Mize and Schultz 1985).

Based on these results, nine treatment combinations representing the extremes in seedling morphologies found in the study, were selected for further laboratory and field testing. The selected treatments included three levels of density and three levels of N application. The actual densities varied some with plot but were the low, middle, and high sowing rates and averaged 135, 220, and 297 seedlings/$m^2$, respectively. The selected N levels were the first, third, and highest levels, or low, 55; medium, 110; and high, 170 kg N/ha, respectively.

Eight to ten seedling shoots (stems and needles) from each plot were clipped on August 6 and December 10 for later chemical analysis. These shoots were pooled for each plot, then dried, ground, and analyzed for N, P, and potassium (K) concentration. The samples were digested in sulfuric acid with copper sulfate added as a catalyst. Nitrogen concentration was determined with an ammonia-specific electrode (Powers and others 1981), P was determined colormetrically (John 1970), and K by atomic absorption spectrophotometry.

On February 20, 1986, about 300 seedlings from each of the 9 selected treatments were carefully hand-lifted for physiological testing. From those lifted, seedlings were selected to span the range in morphologies within a treatment; consequently, each nursery replication was not represented equally. Twenty seedlings from each treatment were randomly assigned to one of three RGP temperatures, 10°, 15°, or 20°C, in the system described by Waldren and others (1985). The rest of the seedlings were used in additional tests, which will be reported on in another article.

The seedlings were cold-stored until the RGP tests began on April 28, 1986. The root volume and height of each seedling were measured; then the seedlings were potted in sand, and no nutrients were added during the 28-day test period. At the end of the test, RGP was measured as the number of new roots greater than 1 cm in length.

The effects of nutrition and seedbed density on the August and December content of N, P, and K in shoots were determined for the selected treatments for each element using analysis of variance. For treatment factors that resulted in significant differences, orthogonal polynomials were used to evaluate trends among levels of that factor. For evaluating the effect of density, actual plot densities were used in the polynomials.

The effects of seedbed density and applied N on RGP of the nine selected treatments were tested using multiple linear regression for each temperature regime. The regression models were developed using actual plot densities, amount of N applied, density squared, N squared, and density x N as the independent variables, and the number of new roots as the dependent variable. Similar models were developed using seedling root volume, height, their squared values, and the interaction term as independent variables to examine the effect of seedling morphology on RGP. The significant factors were then combined into one multiple linear regression model for each temperature to determine how much of the variation in RGP could be explained by the experimental treatments.

## RESULTS AND DISCUSSION

### Seedling Morphology

Among the December-lifted seedlings, diameter, height, and root volume were all significantly affected by seedbed density and N, but not by P (table 1). Phosphorus was probably not important because a sufficient base level existed at the start of the study. There were no significant interactions among treatment factors for any of the characteristics measured. Overall means for the study were diameter, 4.0 mm; height, 186 mm; and root volume, 2.3 $cm^3$. Within seedbed density and nitrogen, orthogonal polynomial comparisons were used to examine the relationships among levels of those treatment factors. Highly significant, linear relationships were obtained between density and each of the characteristics measured. Seedling diameter and root volume decreased with increasing density, while height increased with density. The relationship between density and root volume was much stronger than the relationship between density and diameter. Diameter and root volume also had highly significant linear relationships with total N applied, increasing as N increased. For height, however, there was a significant second degree regression with N. Seedlings grown under the third level of N (110 kg/ha) were taller than those grown with more (170 kg/ha) or less (55 or 85 kg/ha) N. Although we did not determine the reason for that response, it may have been a result of the reduction in soil pH caused by the ammonium sulfate used as the source of N. At the highest fertilizer rate, about 186 kg/ha of sulfur was applied along with the 170 kg/ha of N. It may also have been a result of an increase in the salt level in the soil, again caused by the fertilizer used.

### Shoot Nutrient Concentration

The nutrient concentrations in the stems and needles of seedlings from the selected treatments sampled in August and December were affected by total N applied and, in the case of K concentration in December, by seedbed density (table 2). Among the August-sampled seedlings, the only significant relationship was between applied N and N concentration, with the concentration of N in the stem and foliage increasing linearly with increasing N level. The August sample was taken 11 days after the last application of N in the experiment. Nitrogen concentration, therefore, was probably at a level higher than during the rest of the growing season. It did, in fact, drop across all levels of both treatment factors when sampled again in December. However, by December, N concentration had dropped much more in seedlings from the medium level of N application (110 kg/ha). A significant second degree regression resulted with seedlings from both the low N (55 kg/ha) and high N (170 kg/ha) treatments having higher N concentrations than those from the medium N treatment. This pattern is opposite of that for height, i. e., seedlings with the lowest N concentration in December were the tallest. Therefore, although the N concentration was lower in the tallest seedlings, total N content may not have been.

As the amount of N fertilizer was increased, December-sampled seedlings had a significant linear decline in P concentration (table 2). The concentration of K in the stems and foliage of December-sampled seedlings showed a similar significant linear decline with increasing N fertilization. Moreover, there was a significant linear increase in K concentration with increasing seedbed density. Therefore, the seedlings with the highest concentration of K were from the high density, low N treatment, and those with the lowest K concentration were from the low density, high N treatment.

Boyer and South (1985) reported nutrient concentrations of loblolly pine seedlings sampled from 21 nurseries between November and January. They analyzed foliage and stems separately. Although the species and sample techniques differed, a comparison between our results and their foliage values is informative. They reported foliar N concentrations of between 9.2 and 22.4 g/kg, with a median value of 16.4. Our overall December N concentration was 14.2 g/kg. The P concentration in their study was between 1.2 and 3.0 g/kg, with a median of 2.1. In our study, P averaged 1.6 g/kg. For K, they reported values of between 8.2 and 14.7 g/kg, with a median concentration of 11.2. Our seedlings had markedly less K, with an average of 5.6 g/kg and a maximum of only 6.4 for seedlings from the high density, low N treatment. Boyer and South (1985) gave no indication of what concentration may represent a deficiency of a particular nutrient, or how the nutrient levels related to seedling quality.

Fowells and Krauss (1959) studied the effects of applied N and P on nutrient uptake of loblolly and Virginia pine (*P. virginiana* Mill.)

Table 1.--The effects of different levels of phosphorus, seedbed density, and nitrogen, on the morphology of bare-root shortleaf pine seedlings

| Treatment factor and level | Characteristic | | |
|---|---|---|---|
| | Root collar diameter | Height | Root volume |
| Phosphorus (1,3)[a] | | | |
| -----p/m------- | ----mm---- | ---mm--- | ---$cm^3$--- |
| 54 | 4.0 | 185 | 2.3 |
| 81 | 4.1 | 187 | 2.3 |
| | .09 ns[b] | .10 ns | .01 ns |
| Density (4,24) | | | |
| ---/$m^2$--- | | | |
| 141 | 4.6 | 169 | 3.3 |
| 218 | 4.1 | 185 | 2.4 |
| 269 | 3.8 | 189 | 2.0 |
| 296 | 3.9 | 197 | 2.0 |
| 296 | 3.8 | 190 | 2.0 |
| | 1:94.48***[c] | 1:14.61*** | 1:189.72*** |
| Nitrogen (3,90) | | | |
| ---kg N/ha--- | | | |
| 55 | 3.9 | 186 | 2.2 |
| 85 | 4.0 | 187 | 2.2 |
| 110 | 4.0 | 192 | 2.2 |
| 170 | 4.2 | 179 | 2.6 |
| | 1:15.64*** | 2:6.32* | 1:21.39*** |
| Overall means | 4.0 | 186 | 2.3 |

a/ Numbers in parentheses are degrees of freedom for each factor in the split-split plot design with 4 replications.

b/ F statistic and: ns=not significant, * = $P < 0.05$ , *** = $P < 0.001$.

c/ Degree of orthogonal polynomial, F statistic, and significance of the regression among levels.

grown in sand culture. Their digestion methods were similar to ours, but they also ran separate analyses for needles and stems. Nevertheless, their results were similar to ours in that foliar N concentrations increased with N fertilization, while the concentration of K declined. Based on their sand culture experiments and information from naturally grown trees, they concluded that loblolly and Virginia pines do not differ in their requirements for N and P. Furthermore, they concluded that concentrations of 17 to 23 g/kg of N and 1.4 to 1.6 g/kg of P in the foliage in December indicates satisfactory nutrition. Based on these results, it appears likely that our shortleaf pine seedlings received at least marginally sufficient nutrition in all our selected treatment combinations.

Root Growth Potential

In this study, RGP was evaluated at three root zone temperatures -- 10°, 15°, and 20°C (table 3). At 10°C, the number of new roots ranged from an average of 0.2 for the high density, high N treatment to 1.0 for two treatments, low density, high N and medium density, low N. The overall mean of the 180 seedlings tested at this temperature was 0.6 new roots. The coefficient of variation (CV) was very high at 162 percent. The multiple linear regression did not show a significant ($P<0.05$) relationship between the number of new roots and either density or level of applied N. A similar regression with root volume and height also did not show a significant ($P<0.05$) relationship between RGP and either morphological characteristic. At 10°C, RGP could not be related to nursery treatment. However, Carlson (1986) was not able to show significant differences among differences among half-sib families of loblolly pine at 10°C when using a similar experimental design. If the design was not sensitive enough to detect genetic differences, it probably could not differences due to cultural treatment either.

Table 2.--August and December nutrient concentrations in the stems and needles of shortleaf pine seedlings grown under different regimes of seedbed density and N fertilization

| Treatment factor and level | Sample month/nutrient | | | | | |
|---|---|---|---|---|---|---|
| | August | | | December | | |
| | N | P | K | N | P | K |
| Density (2,6)[a] | | | | | | |
| ---/m²--- | ---g/kg--- | | | ---g/kg--- | | |
| 135 | 17.9 | 1.4 | 10.5 | 14.9 | 1.7 | 5.3 |
| 220 | 17.4 | 1.3 | 9.8 | 13.7 | 1.6 | 5.4 |
| 297 | 17.2 | 1.4 | 9.7 | 14.1 | 1.6 | 5.9 |
| | .73 ns[b/] | .76 ns | 1.19 ns | 1.95 ns | .30 ns | 1:10.82*[c/] |
| Nitrogen (2,18) | | | | | | |
| ---kg N/ha--- | | | | | | |
| 55 | 16.3 | 1.4 | 10.2 | 14.7 | 1.8 | 5.9 |
| 110 | 17.3 | 1.4 | 9.9 | 13.3 | 1.7 | 5.4 |
| 170 | 18.9 | 1.3 | 9.9 | 14.7 | 1.4 | 5.5 |
| | 1:42.98*** | 3.44 ns | .25 ns | 2:8.85** | 1:24.94*** | 1:22.29*** |
| Overall means | 17.5 | 1.3 | 10.0 | 14.2 | 1.6 | 5.6 |

a/ Numbers in parentheses are degrees of freedom for each factor in the split-split plot design with 4 replications.

b/ F statistic and: ns=not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

c/ Degree of orthogonal polynomial, F statistic, and significance of the regression among levels.

The value in using 10°C was in determining the threshold temperature for an RGP response in shortleaf pine.

At a root zone temperature of 15°C, there was a significant ($P<0.01$) but weak regression ($r^2 = .082$) between the number of new roots and density, total N applied, and the interaction between density and N (fig. 1). The regression was $Y = 3.54806 + .0374X_1 - .10955X_2 - .00045X_3$, where Y = number of new roots >1 cm long, $X_1$ = density, $X_2$ = total N applied, and $X_3$ = density x total N. RGP ranged from a low average of 4 new roots in the medium density, high N treatment to 12.8 in the low density, high N treatment (table 3). The overall mean of the 180 seedlings tested was 6.0 new roots, with a CV of 109 percent.

The significant interaction at this temperature was largely a result of the high mean RGP for the low density, high N treatment. In that treatment one seedling had 49 new roots, twice as many as any other seedling in the treatment. With that seedling removed from the data set, the regression and the interaction were still significant ($P<0.05$). With respect to density, RGP at 15°C generally increased with decreasing density at high levels of applied N, but was less affected as the amount of N was reduced. However, at high density, high N resulted in the poorest predicted RGP.

When the number of new roots was examined in relation to seedling root volume and height, a positive low linear relationship ($r^2 = .127$) with root volume was found. The regression was $Y = 1.79541 + .75053X$, where Y = number of new roots and X = root volume. The number of new roots was not related to height. Although the regression between RGP and root volume accounted for only 12.7 percent of the variation, it was highly significant ($P<0.001$).

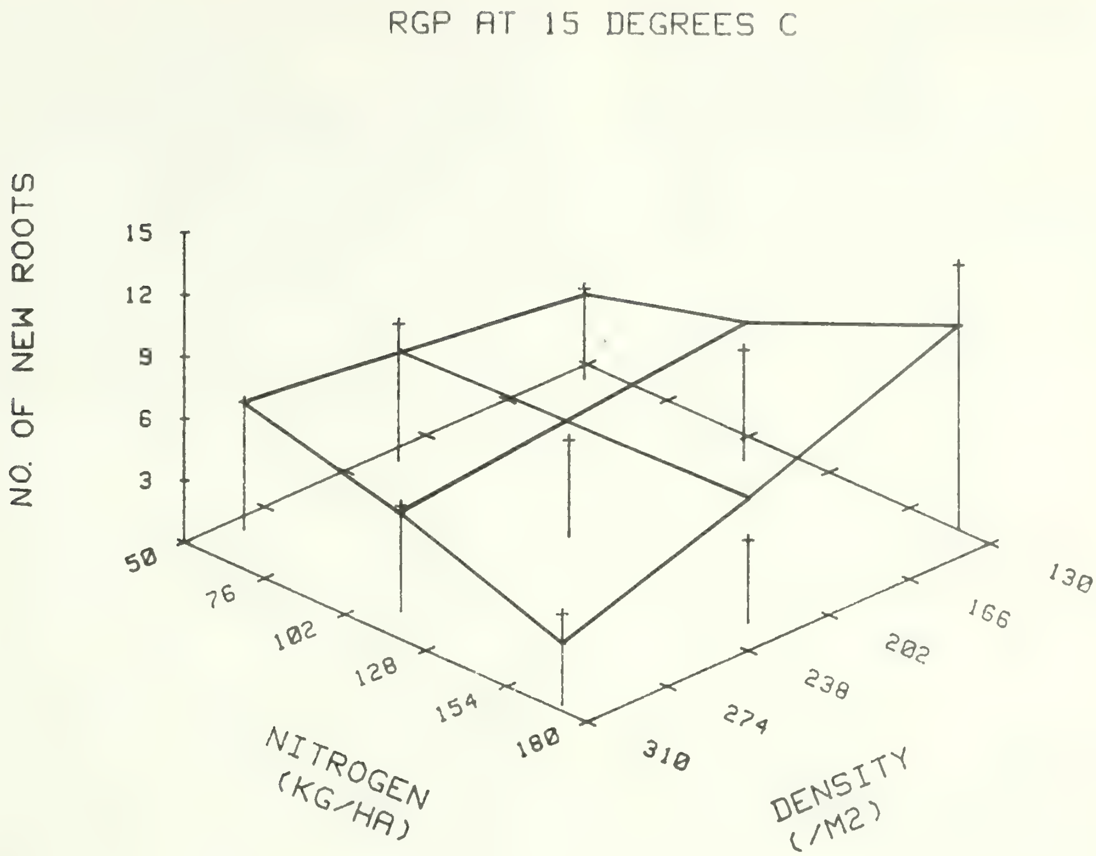


Figure 1.--Actual (+) and predicted (response surface) number of new roots after 28 days at 15°C for shortleaf pine seedlings grown at three densities and fertilized at three levels of nitrogen.

Because both root volume and RGP were strongly related to density, and to some degree to N, the results of the two regressions are not additive. However, when root volume was added to the density-nitrogen model, a highly significant ($P<.001$) multiple regression resulted that explained 17.1 percent of the total variation of RGP. That regression model was $Y = 8.54393 + .69618X_1 + .04604X_2 + .09528X_3 - .00041X_4$, where Y = number of new roots, $X_1$ = root volume, $X_2$ = density, $X_3$ = total N, and $X_4$ = density x total N.

At 20°C, a significant ($P<0.001$) regression RGP = .155) resulted among RGP and density, total N, (total N)$^2$, and the density x N interaction (fig. 2). The regression was $Y = 12.33914 + .06726X_1 - .28012X_2 + .00188X_3 - .00047X_4$, where Y = number of new roots, $X_1$ = density, $X_2$ = total N, $X_3$ = (total N)$^2$, and $X_4$ = density x total N. Among the treatments, RGP averaged from 3.0 for the high density, medium N treatment to 17.7 for the low density, high N treatment (table 3). The best treatment at 20°C was also the best at 15°C. The overall mean of the 180 seedlings was 11.7 new roots and the CV was 84 percent. As at 15°C, there was a significant ($P<0.001$), positive linear relationship ($r^2 = .073$) between the number of new roots and root volume. At 20°C, regression was $Y = 6.69326 + .87163X$, where Y = number of new roots and X = root volume.

When root volume was added to the density-nitrogen multiple linear regression model, a highly significant ($P<.001$) relationship was found. The model, which explained 21.1 percent of the variation in RGP at 20°C, was $Y = 4.07003 + .85718X_1 + .07997X_2 - .25077X_3 + .00167X_4 - .0046X_5$, where Y = number of new roots, $X_1$ = root volume, $X_2$ = density, $X_3$ = total N, $X_4$ = (total N)$^2$, and $X_5$ = density x total N.

One interesting result at this temperature was the quadratic relationship between RGP and N fertilization. It shows the same recurring pattern among the levels of N as does seedling height (table 1) and December concentration of N in the stems and needles (table 2). That is, when compared across all densities, the medium level of

Table 3.--The average number of new roots produced by density and nitrogen-treatment after 28 days at three root-zone temperatures

| Treatment | Root zone temperature (°C) 10 | 15 | 20 |
|---|---|---|---|
| | ----No. new roots > 1 cm------ | | |
| Low density | | | |
| low N | 0.6 | 4.4 | 8.3 |
| medium N | .4 | 5.4 | 5.4 |
| high N | 1.0 | 12.8 | 17.7 |
| Medium density | | | |
| low N | 1.0 | 6.6 | 11.8 |
| medium N | .5 | 4.7 | 14.4 |
| high N | .4 | 4.0 | 14.7 |
| High density | | | |
| low N | .5 | 6.2 | 14.5 |
| medium N | .5 | 5.1 | 3.0 |
| high N | .2 | 4.4 | 15.9 |
| Overall means | .6 | 6.0 | 11.7 |

N used in this study (110 kg/ha) resulted in the tallest seedlings but those with the lowest N concentration in their shoots and with the lowest RGP at 20°C. However, although the regression resulted in a very strong quadratic relationship, the actual data for the medium level of N are not consistent with the predicted trend (fig.2). The two lowest values of RGP at 20°C came from the medium N treatment at the extreme densities, but RGP from the medium N treatment at the medium density was among the best (table 3).

## CONCLUSIONS

Seedbed density and N fertilization have significant impacts on the morphological and physiological quality of shortleaf pine seedlings. Within the levels of the treatment factors used in this study, diameter, root volume, height, nutrient status, and RGP were all affected by either density or the amount of N applied. The morphological attributes and RGP were affected by both, while nutrient status was determined primarily by the level of applied N.

New root initiation and elongation varied with root zone temperature. At new root growth was not related to either nursery treatments or seedling morphology. But at 15° and 20°C, RGP was related to both nursery treatments and seedling root volume. The relationship among density, root volume, and RGP is generally that lower density results in larger root volumes and higher RGP. The results also indicate that N fertilization in the nursery has an important impact on RGP. However, the data do not clearly elucidate the nature of the relationship between N and RGP. The use of half-sib family material, or some other method of reducing the high variability in RGP, would markedly improve the chances of explaining the relationships between nursery cultural practices and RGP. The data do show that increasing the amount of applied N can increase root volume and thus compensate somewhat for increasing density.

Several aspects of this study are still ongoing, and those results are needed to make recommendations about target seedling specifications and the nursery practices needed to grow them. However, these preliminary results suggest that seedbed densities well below the maximum used in this study will provide the morphological and physiological attributes needed for early root growth and establishment after out planting. Furthermore, a low level of applied N may be sufficient if the lower densities are used.

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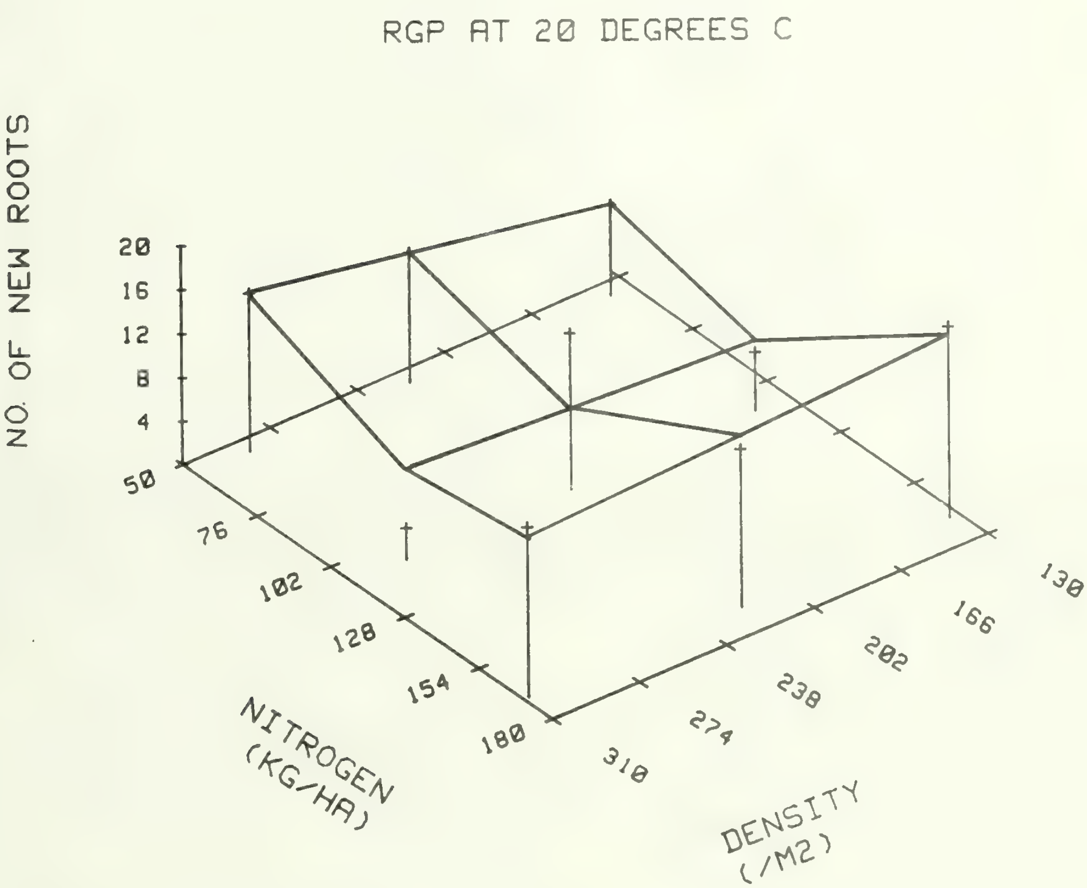


Figure 2.--Actual (+) and predicted (response surface) number of new roots after 28 days at 20°C for shortleaf pine seedlings grown at three densities and fertilized at three levels of nitrogen.

# RELATIONSHIPS OF MORPHOLOGICAL ROOT AND SHOOT CHARACTERISTICS TO THE PERFORMANCE OF OUTPLANTED BAREROOT AND CONTAINERIZED SEEDLINGS OF LOBLOLLY PINE[1/]

Jean A. Wilder-Ayers and John R. Toliver[2/]

Abstract.--Morphological root and shoot characteristics were measured on 20 half-sib families of bareroot and containerized loblolly pine (Pinus taeda L.) seedlings 9 months after germination. Bareroot seedlings were grown in nursery beds; containerized seedlings in a greenhouse. Ten seedlings from each family were chosen at random for measurement from each of five replications in both the nursery and greenhouse. Other seedlings were outplanted in the field. Simple linear correlations between root and shoot characteristics and first-year field performance of outplanted seedlings were calculated. Bareroot seedling shoot and root characteristics were generally positively correlated with first-year height but negatively correlated with height growth and survival. Only three characteristics of the containerized seedlings were significantly correlated with field performance of the outplanted trees, probably as a result of the uniformity of the containerized seedlings. Bareroot seedlings exhibited no significant family variation in height, height growth, or survival. In contrast, family variation among containerized seedlings was highly significant for first-year height and height growth. In this study, the containerized seedling progeny test did not reflect the results of the bareroot progeny test.

## INTRODUCTION

Morphological seedling characteristics have been examined since the early 1920's to assess seedling quality and field performance (Wakeley 1954). Characteristics of bareroot seedlings grown in nursery beds can differ from those of containerized seedlings grown in greenhouses. Consequently, morphological characteristics used to predict field performance of outplanted seedlings may differ with the method of seedling production.

The use of containerized seedlings has increased and is now a viable alternative to the use of bareroot stock. Although containerized stock may shorten the time span for growing seedlings, tree improvement researchers have not confirmed that the growth of containerized seedlings is equal or superior to that of bareroot seedlings grown in nursery beds (Kellison and Lea 1983). Both types of planting stock have advantages.

The primary advantages of bareroot stock are its relatively low cost of production and ease of handling and transport. Nursery-grown seedlings also require less technical knowledge and daily attention and are less conducive to disease and nutritional imbalances than containerized seedlings grown in a greenhouse (Barnett 1978).

On the other hand, containerized seedlings have several advantages. The most important is increased seedling uniformity. With proper management, raising seedlings in containers can bypass problems encountered in nursery beds such as variations in germination and soil texture, low spots in the nursery beds, and problems with weeds which may cause a lack of uniformity (van Buijtenen and Lowe 1982). Containerized seedlings can survive and grow better than

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nursery stock despite the fact that they are often younger at outplanting (Barnett 1975). Root systems of the containerized seedlings remain intact, whereas bareroot seedlings need several months to regenerate roots lost during lifting and pruning (Barnett 1978).

Large investments in planting both types of stock support the necessity for research on root form (Tinus 1978). Stein et al. (1975) stated that the effect of planting methods (bareroot or containerized) on subsequent seedling root systems, survival, and growth is an important aspect of reforestation that has not been completely evaluated. According to Leaf et al. (1978), the ability to establish healthy root systems is crucial for successful outplanting. Therefore, root mass is critical to seedling field performance (Duryea and Landis 1984).

This research was a part of a larger study designed to evaluate the extent of genetic variation among root systems of bareroot and containerized loblolly pine seedlings (Wilder-Ayers 1986). In this paper, morphological root and shoot characteristics of bareroot and containerized seedlings were compared to assess their effects on survival and growth one year after outplanting. Another objective of this study was to determine if a containerized progeny test would be reflective of family performance when the same progeny were outplanted as bareroot seedlings..

## METHODS

Seed from 20 open-pollinated loblolly pine (Pinus taeda L.) families were provided by the Western Gulf Forest Tree Improvement Cooperative. The seedlings were grown at Louisiana State University (LSU) in Baton Rouge. One-half of the seed were sown in nursery beds in April 1984 and grown as bareroot seedlings. The remaining seed were planted in June and grown in Styroblock-8 containers in a greenhouse for 9 months. The plot layout for each method of seedling production was a randomized block design, with 5 blocks, and 20 families within each block.

In January 1985, 10 seedlings from each family in each replication were randomly selected for root and shoot measurements. These seedlings were carefully lifted from the nursery bed or extracted from their containers. Variables examined included taproot length, number of major lateral roots, average length of the five longest lateral roots, root forking, root collar diameter, shoot length, and root and shoot volumes (Wilder-Ayers 1986). A major lateral root was defined as one with a diameter of 1 mm or more; however, on some seedlings all lateral roots were smaller than 1 mm, thus major lateral roots became a subjective classification. The displacement method as described by Burdett (1979) was used to measure volumes. After taking the initial measurements, taproots and laterals of the bareroot seedlings were pruned to 20 and 5 cm, respectively and additional measurements were taken.

The remaining seedlings were outplanted at Lee Memorial Forest in Washington Parish, Louisiana. The bareroot seedlings were root-pruned and planted in late January 1985, and the containerized seedlings were planted in mid-March. The soil was classified as a Ruston fine sandy loam (USDA Soil Conservation Service 1970). The plantation design consisted of a split-split-plot treatment arrangement in a randomized block. Twenty blocks were split by seedling type (bareroot and containerized) and five seedlings per family were planted in rows within each type.

Initial height of the seedlings was measured after outplanting. Seedling survival was recorded in May 1985. Height was measured again in November 1985 to evaluate first-year growth, and survival was determined. Correlations between seedling root and shoot characteristics and variables measured in the field were calculated to examine relationships between seedling characteristics and the first year's growth and survival of seedlings.

## RESULTS AND DISCUSSION

All characteristics of the bareroot seedlings were significantly greater ($p \leq 0.01$) than those of the containerized seedlings with the exception of the number of laterals (Tables 1 and 2). Because the differences in means between the two methods of seedling production were so large, subsequent analyses of the two seedling production types were conducted separately.

### Performance of Bareroot Seedlings

All bareroot seedling shoot characteristics were positively correlated with first-year height growth and survival (Table 3). The same general trends were true of the root characteristics. This indicates that the larger the seedling at planting time, the taller it was at the end of the first growing season. However, survival and height growth decreased when larger seedlings were planted. Normally, this would not be true unless the shoot-root ratio was too large which we believe to be the major cause of poor survival (39 percent) and growth in this study. The shoot-root volume ratio of the bareroot seedling was 4.28:1 (Table 1) before pruning and 7:1 after the roots were pruned to operational planting size. Wakeley (1954) stated that a Grade 1 plantable seedling should have a shoot-root ratio no greater than 2.5:1. Seedlings with larger ratios such as those in this study usually do not perform well in the field. In order to minimizing biasing normal development of the seedlings, no top or root pruning was performed in the nursery bed, so the only means of slowing growth was by withholding water. However, rainfall in Baton Rouge was sufficient to allow optimal growth and the seedlings grew to a much larger size than

Table 1. Comparison of the means of characteristics measured on loblolly pine seedlings grown under two methods of seedling production (Wilder-Ayers 1986).

| Seedling characteristic | Production method Bareroot | | Containerized |
|---|---|---|---|
| Shoot | | | |
| Shoot length (cm) | 36.91 | ** | 23.01 |
| Shoot volume (ml) | 27.90 | ** | 4.63 |
| Total shoot-root vol. ratio | 4.28 | ** | 1.99 |
| Shoot-root vol. ratio (pruned) | 7.01 | | --[1] |
| Root | | | |
| Root collar diameter (cm) | 0.63 | ** | 0.34 |
| Total taproot length (cm) | 24.93 | ** | 14.36 |
| Pruned taproot length (cm) | 16.98 | | -- |
| Number major lateral roots | 16.07 | ** | 21.61 |
| Average lateral length (cm) | 31.50 | ** | 15.28 |
| Total root volume (ml) | 6.72 | ** | 2.31 |
| Pruned root volume (ml) | 3.76 | | -- |

**Means are significantly different between bareroot and containerized seedlings ($p \leq 0.01$).

[1]Containerized seedling root systems were not pruned.

Table 2. Comparison of means of characteristics measured on bareroot and containerized loblolly pine seedlings after one year in the field.

| Characteristics | Bareroot | | Containerized |
|---|---|---|---|
| Height[1] at outplanting (cm) | 29.30 | ** | 23.13 |
| First-year height (cm) | 40.98 | * | 36.76 |
| First-year height growth (cm) | 11.68 | * | 13.62 |
| Survival in May (percent) | 55.60 | ** | 99.00 |
| First-year survival (percent) | 38.60 | ** | 90.00 |

[1]Mean height and growth only on those seedlings surviving at the end of the first growing season.

**,*Means are significantly different between bareroot and containerized seedlings ($p \leq 0.01$) and $p \leq 0.05$ respectively.

desired. The mean height of the seedlings was 36.9 cm, the pruned taproot 16.98 cm long, and mean root collar diameter 0.63 cm (Table 1). The desired seedling height was 25.4 cm. Thus, the seedling height was 45 percent greater.

Because the seedlings were so large and shoot-root ratios out of proportion, the relationships of the bareroot seedling characteristics with field performance should be viewed with caution. Results of this study further substantiate that seedling morphological shoot and root characteristics are correlated with field performance and that the shoot-root ratio is very important for survival and growth of bareroot seedlings.

## Performance of Containerized Seedlings

In contrast to the bareroot seedlings, only three root and shoot characteristics of containerized seedlings were correlated to field performance of the outplanted trees (Table 4). The lack of correlation was probably due to the uniformity of the containerized seedlings, especially their confined root systems. The number of lateral roots was positively correlated with survival but not to height growth. Kormanik (1985) suggested that the number of lateral roots on sweetgum (*Liquidambar styraciflua* L.) seedlings could be used to indicate performance after outplanting.

Table 3. Correlations between loblolly pine bareroot seedling shoot and root characteristics and measurements taken after one year in the field.

| Seedling characteristics | First-year field measurements | | |
|---|---|---|---|
| | Height | Height growth | Survival |
| | - - - Correlation coefficients - - - | | |
| Shoot | | | |
| Shoot length (cm) | 0.54** | -0.28** | -0.32** |
| Shoot volume (ml) | 0.47** | -0.32** | -0.37** |
| Total shoot-root vol. ratio | 0.52** | -0.32** | -0.43** |
| Pruned shoot-root vol. ratio | 0.51** | -0.25* | -0.28** |
| Root | | | |
| Root collar diameter (cm) | 0.27** | -0.20 | -0.18 |
| Total taproot length (cm) | 0.16 | -0.25* | -0.36** |
| Pruned taproot length (cm) | 0.27** | -0.22 | -0.24* |
| Number major lateral roots | 0.26* | -0.15 | -0.11 |
| Average lateral length (cm) | 0.12 | -0.10 | -0.08 |
| Total root volume (ml) | 0.24* | -0.21 | -0.17 |
| Pruned root volume (ml) | 0.30** | -0.22 | -0.24* |

*Simple linear correlation coefficients were significant at the 0.05 level.

**Simple linear correlation coefficients were significant at the 0.01 level.

Survival of the containerized seedlings (90 percent) was over twice as great as that of the bareroot seedlings (Table 2). We believe the higher survival of the containerized seedlings over the bareroot seedlings was most likely a function of the optimal size and condition of the seedlings. The mean shoot-root volume ratio of the containerized seedlings was 2:1, a more desirable ratio than that of the bareroot seedlings.

Although both mean initial height of the containerized seedlings and height at the end of the first growing season were lower than the mean heights of the bareroot seedlings, containerized seedlings exhibited greater average height growth. This implies that the containerized seedlings were able to adjust to field conditions and to continue growth at faster rates than bareroot seedlings.

## Operational Progeny Testing

The bareroot seedlings exhibited no significant family variation in height, height growth, or survival. In contrast, family variation among the containerized seedlings was highly significant for height and height growth at the end of the first growing season. Survival was high for the containerized seedlings and no significant variation among families was apparent.

The contrast in family variation between seedlings produced as bareroot versus containerized stock indicates that establishing a progeny test from one type of seedling versus another can have a profound effect on the outcome of the test. In this case, the disproportionate size of the bareroot seedlings greatly influenced survival and growth and made the test virtually unuseable for genetic purposes. However, the containerized test was a viable progeny test. The seedlings were uniform in size and quality and survival was high. An underlying objective of this study was to determine if a containerized seedling progeny test would reflect family performance when progeny were outplanted as bareroot seedlings. In this study, the containerized test did not reflect the results of the bareroot seedling progeny test, a test which theoretically was similar to operational planting. However, the bareroot seedlings planted in this study were not the desired seedling size; thus, the results of this comparison should be viewed with caution.

## CONCLUSIONS

Bareroot seedling shoot and root characteristics were generally positively correlated with first-year height but negatively correlated with height growth and survival. However, because the average bareroot seedling in this study was larger than the optimum, the relationships should be viewed with caution. We believe the shoot-root ratio was an important factor in the poor survival and growth of the bareroot seedlings.

Table 4. Correlations between loblolly pine containerized seedling shoot and root characteristics and measurements taken after one year in the field.

| Seedling characteristics | First-year field measurements | | |
|---|---|---|---|
| | Height | Height growth | Survival |
| | - - - Correlation coefficients - - - | | |
| Shoot | | | |
| Shoot length (cm) | 0.08 | -0.26* | -0.08 |
| Shoot volume (ml) | -0.07 | -0.05 | -0.09 |
| Total shoot-root vol. ratio | 0.07 | -0.03 | 0.00 |
| Root | | | |
| Root collar diameter (cm) | -0.07 | -0.11 | -0.20 |
| Total taproot length (cm) | 0.24* | 0.19 | -0.07 |
| Number major lateral roots | 0.09 | -0.04 | 0.29** |
| Average lateral length (cm) | 0.07 | 0.10 | -0.04 |
| Total root volume (ml) | -0.16 | -0.05 | -0.18 |

*Simple linear correlation coefficients were significant at the 0.05 level.

**Simple linear correlation coefficients were significant at the 0.01 level.

Only three characteristics of the containerized seedlings were significantly correlated to field performance of the outplanted seedlings. The lack of correlation was probably due to the uniformity of the containerized seedlings.

Mean survival at the end of the first growing season was 39 percent for the bareroot seedlings and 90 percent for the containerized seedlings. The bareroot seedling shoot-root ratio was apparently too large (7:1) which resulted in poor survival and growth. The shoot-root ratio of the containerized seedlings was more optimal (2:1) and survival and growth was superior to the bareroot seedlings.

Bareroot seedlings exhibited no significant family variation in height, height growth, or survival. Genetic variation may have been masked by the problems encountered with the size of the seedlings. In contrast, family variation among containerized seedlings was highly significant for first-year height and height growth. In this study, the containerized seedling progeny test did not reflect the results of the bareroot seedling progeny test.

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# EFFECTION OF CARBON DIOXIDE ENRICHMENT ON GROWTH AND FIELD SURVIVAL OF CONTAINER-GROWN PINUS TAEDA L. SEEDLINGS[1]

William A. Retzlaff, Ansel E. Miller and Joe E. Toler[2]

ABSTRACT.--This investigation examined some effects of increased atmospheric carbon dioxide levels on container-grown loblolly pine (*Pinus taeda* L.) seedling growth and development. Seedlings were grown in environment chambers supplied with carbon dioxide concentrations of 175, 350, 700, and 1400 ppm. A 4 x 4 Latin square experimental design with four 90-day replications and four environment chambers was employed. At ten-day intervals during each replication, a sample of 9 seedlings from each treatment was used to quantify seedling growth and development. Following completion of each replication, 100 seedlings from each treatment were out-planted to determine field survival.

Seedling morphology was found to be significantly ($\alpha = 0.05$) influenced by increasing carbon dioxide concentration. Total seedling height, root collar diameter, and stem, shoot, root and total dry weights all increased with increasing carbon dioxide concentration. Response analysis of 90-day results suggests that maximum growth occurs when carbon dioxide concentration is approximately 1000 ppm. No differences in field survival occurred in the first year out-planting from replications 1, 2 and 3 (Survival > 77% in all treatments). Another replication will be evaluated for survival after completion of a growing season.

## INTRODUCTION

Fertilization of forest tree seedlings has generated considerable interest. Most research has dealt specifically with mineral nutrient fertilization for bare-root seedling production. However, production of container-grown forest tree seedlings is being explored because it presents opportunities to supplement bare-root seedling production (Raisch, 1981). Beneficial features of container-grown forest tree seedlings include uniform growth rates, fast crop rotation, extended planting seasons and good field performance (Hahn, 1981). Furthermore, some species such as true firs, hemlock, redwood, etc., may be easier to grow in containers than in bare-root nurseries.

Most container-grown tree seedlings are produced in greenhouses. The greenhouse environment can be controlled and some growth factors can be optimized (Tinus, 1974; Tinus and McDonald, 1979). When water and mineral nutrients are optimal, an increase in carbon dioxide concentration is usually accompanied by at least a temporary increase in growth (Kramer, 1981). Increasing atmospheric carbon dioxide concentrations can be considered analagous to fertilization.

Atmospheric carbon dioxide enrichment has been used primarily in agricultural crops with less emphasis on woody plant species. Previous research on the effects of atmospheric carbon dioxide enrichment on coniferous species has utilized white pine (*Pinus strobus* L.), ponderosa pine (*P. ponderosa* Laws), blue spruce (*Picea pungens* Engelm.), Douglas-fir (*Pseudotsuga menziesii* Franco), Scotch pine (*P. sylvestris* L.), lodgepole pine (*P. contorta* Douglas), and sitka spruce (*P. sitchensis* [Bong.] Carr.) (Funsch *et al.*, 1970; Tinus, 1972; Purohit and Tregunna, 1976; Alden, 1971; Canham and McCavish, 1981). Generally, these are northern and western species; the major southern species have not been studied.

Some information concerning growth of loblolly pine seedlings in enriched carbon dioxide atmospheres does exist (Tolley, 1982; Rogers *et al.*, 1983). These investigations were primarily concerned with the effects of rising global atmospheric carbon dioxide on living systems. The use of carbon dioxide fertilization to enhance growth of container-grown loblolly pine seedlings is an area that needs additional study.

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During photosynthesis, carbon dioxide molecules are continually removed from the air surrounding plants and fixed into photosynthetic products (Wright and Lemon, 1970). As a result, carbon dioxide concentration decreases in the air near plant surfaces. Even though conditions for photosynthesis may be favorable, this decrease in carbon dioxide concentration is a common cause of suboptimal photosynthetic rates (Salisbury and Ross, 1978). This concept of carbon dioxide depletion is especially important in greenhouse culture. Frequently, greenhouse crops lack enough carbon dioxide for maximal growth. Methods for applying carbon dioxide in the greenhouse have ranged from such things as compost piles to burying dry ice in the soil (Pallas, 1970). Many greenhouses in America have moved into an era of using compressed carbon dioxide or carbon dioxide generated from fossil fuels.

This investigation examined some effects of enhanced atmospheric carbon dioxide levels on growth and development of container-grown loblolly pine seedlings. The primary objectives of this study included: (1) Quantify growth and development of container-grown loblolly pine (P. taeda L.) seedlings in enriched carbon dioxide atmospheres and (2) Determine field survival potential of container-grown loblolly pine seedlings that developed in a carbon dioxide enriched atmosphere.

## MATERIALS AND METHODS

Airtight chambers were used for growing seedlings in enriched carbon dioxide atmospheres. Seedlings in these chambers were periodically sampled to measure the impact of carbon dioxide treatments on seedling growth. After a 90-day growth period, the seedlings were planted in the field.

### Chamber Design

Four insulated growth chambers were constructed using upright freezer bodies with doors removed. Freezer bodies were laid on their back and clear plexiglass sheets, 0.64 cm thick, replaced the doors as chamber tops. Temperature was kept below 27°C inside the chambers by a 9100 btu Carrier® air conditioner placed in an opening cut in one end of the chamber. The air conditioners were sealed from external air by caulking so that only internal air circulation and cooling would occur.

### Carbon Dioxide Monitoring System

Carbon dioxide concentration was controlled by a modification of designs by Patterson and Hite (1975) and Carter (1982). In this system, the growth chambers were connected to a carbon dioxide monitoring system via plastic tubing and solenoid valves that could be opened and closed to allow air passage.

An Apple IIe® microcomputer was programmed, using Basic language, to sequentially open a solenoid valve. A diaphragm pump was used to draw chamber air through the tubing and Drierite® dessicant into an infrared gas analyzer (IRGA) (Beckman® Model 865). The IRGA continually relayed an analog output (0 to 5 volts) to an analog/digital converter (Applied Engineering®) in the computer. Utilizing the Basic program, this volt signal was converted to a ppm carbon dioxide value by the analog/digital converter.

The microcomputer was programmed to take 9 sample values at one second intervals, average them, and compare them to a tenth value. If the average was within 10 ppm of the tenth value, it was accepted. Otherwise, this step was repeated until the programmed condition was met. When the condition was met, the carbon dioxide level was stored in memory for later use. Stored ppm values for each chamber were averaged hourly and printed out on paper.

The accepted carbon dioxide reading was then compared to a programmed concentration (350, 700,... ppm) according to the treatment assigned to that particular chamber. If the sample carbon dioxide value was below the programmed concentration, the microcomputer activated a second solenoid valve connected to a carbon dioxide cylinder and injected pure carbon dioxide into the chamber. The amount and duration of injection was determined by the deficit between the programmed and sample reading. If the sample value for a given chamber was greater than the programmed reading, the sampling solenoid valve was closed. At this time the computer opened the sample solenoid valve of the next growth chamber and the measurement and injection processes were repeated. Growth chambers were monitored sequentially in this manner.

### Carbon Dioxide Treatments

Carbon dioxide concentrations of 175, 350, 700 and 1400 ppm were chosen to be the four programmed set points or treatment rates. Each treatment was randomly assigned to a growth chamber. Since each treatment could only occur in one growth chamber at a time, the entire experiment was repeated four times in order that all treatment rates could occur in all growth chambers. A Latin square design was used so that differences between chambers as well as replications could be removed from experimental error. Length of each replication was 90 days. Two replications (1 and 3) of the experiment were grown under artificial lights (metal halide lamps with light intensities of 650-700 µE $s^{-1}m^{-2}$) indoors using a 14-hour daylength. The other two replications (2 and 4) were grown outdoors in natural light (up to 2000 µE $s^{-1}m^{-2}$) during spring and summer.

Seed and Cultural Treatments

At the beginning of each replication, loblolly pine seeds from an orchard seed source (S.C. State Forestry Commission) were germinated in flats of builder's sand. When radicles were 1-4 cm long, the seedlings were transplanted into 115 cu. cm Leach-cells (Ray Leach "Cone-tainer" Nursery, Canby, Oregon) containing a 2:2:1 mixture of fine grade peatmoss (spaghnum), vermiculite (grade #2), and perlite (particle size 1-3 mm). Three filled trays, each having 98 containers, were then set inside each growth chamber. During each 90-day replication, seedlings were irrigated approximately every 3 days. Periodically, seedlings were supplied with a solution of Peter's 20-20-20 fertilizer with micronutrients (0.5 g/l).

Growth Measurements

Beginning at cotyledon emergence and at 10-day intervals for 90-days, 9 seedlings from each treatment were selected for growth analysis. Total seedling height, root collar diameter, and dry weights of needles, stems and roots were determined for each seedling.

Field Out-planting

At the end of each replication (90-day growth period) 100 seedlings per treatment were planted in the field using dibbles. The first replication was out-planted in a nursery bed at the Clemson University Forestry Department Nursery. Replications 2, 3, and 4 were all out-planted on a rootraked and windrowed upland piedmont site on the Clemson University Experimental Forest. In all out-plantings, twenty trees from each treatment were planted in each of five blocks. Survival of the out-planted seedlings was determined following the end of the first growing season.

## RESULTS AND DISCUSSION

Programmed carbon dioxide treatments were maintained by a monitoring system throughout the experiment period. However, the system provided actual determinations of the mean carbon dioxide concentration in each chamber/treatment combination during each replication (Table I). Carbon dioxide values for treatments 350, 700 and 1400 were near the programmed goals. Unfortunately, actual carbon dioxide values for treatment 175 were close to ambient carbon dioxide levels and consequently, near values for treatment 350. Therefore, the low treatment failed to "starve" the seedlings, which was the initial plan for this treatment.

Seedling measurements for each carbon dioxide treatment were averaged across all 4 replications and plotted over the 90-day growth period. Growth responses were examined using actual mean carbon dioxide treatment values. The typical response to carbon dioxide treatment is illustrated by seedling total dry weight (Figure 1). The ANOVA procedure for a Latin square design showed significant differences in response to atmospheric carbon dioxide enrichment for seedling morphological characteristics. Separation of response did not occur in most cases until 40 days into each replication. Separation at this time was between the two lowest and two highest carbon dioxide treatments. Separation of all 4 carbon dioxide treatments was detected at 70 days, and differences among treatments increased for subsequent sampling periods. However, because there was a significant difference in growth response due to location, that is replications 1 and 3 in artificial light and replications 2 and 4 in natural light, data was divided into two groups according to lighting conditions during each 90-day growth period for further analysis.

Table I. Carbon dioxide concentrations for each chamber (treatment) during each replication.

| Goal | Rep1 | Rep2 | Rep3 | Rep4 | Overall Mean |
|---|---|---|---|---|---|
| | | | ppm | | |
| 175 | 358 | 291 | 390 | 337 | 344 |
| 350 | 476 | 402 | 424 | 397 | 425 |
| 700 | 790 | 696 | 868 | 841 | 799 |
| 1400 | 1201 | 1147 | 1394 | 1374 | 1279 |

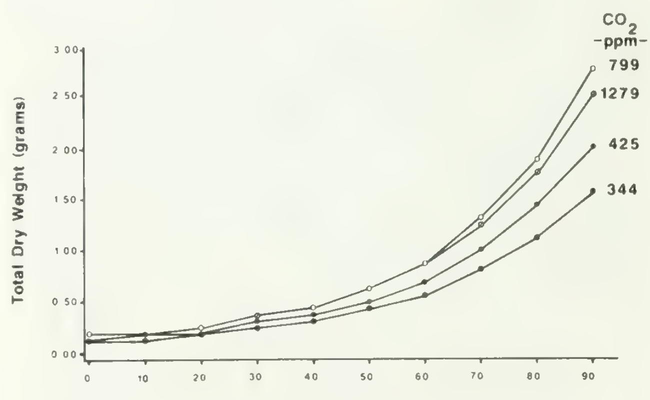


Figure 1. Total dry weight response of seedlings exposed to four carbon dioxide treatments over a 90-day period.

Seedling total dry weight is again used to illustrate the typical response relationship to carbon dioxide enrichment under natural light conditions (Figure 2). Utilizing a parabolic relationship function, actual carbon dioxide values and corresponding growth achieved in each chamber showed a very good least-squares fit. From this equation the maximum dry weight of 3.2 grams occurs at 979 ppm carbon dioxide. This value is approximately 60% greater than the dry weight achieved at carbon dioxide concentrations approximating ambient air.

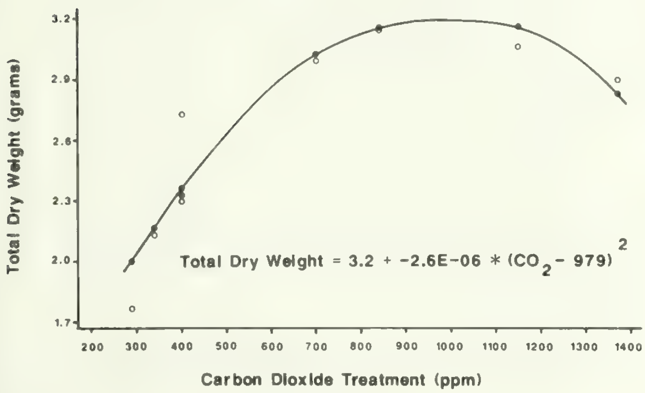


Figure 2. Total dry weight of seedlings at 90-days when exposed to four carbon dioxide treatments using natural light conditions (o = observed values, ● = estimate values).

Utilizing the same approach to describe responses of each morphological characteristic measured in this study, estimates were made of the optimum carbon dioxide concentration and maximum expected growth of container-grown loblolly pine seedlings. Under natural light conditions, optimum growth occurs in all cases at approximately 1000 ppm carbon dioxide levels (Table II). Under artificial light conditions, 1000 ppm again seems to be the best level for optimum growth (Table III). However, the maximum growth under artificial light intensities was less than that under natural light conditions.

Finally, the field survival of seedlings grown under atmospheric carbon dioxide enrichment was similar for all carbon dioxide pretreatments with the exception of replication 3. Field survival for replication 2 and 3 was very good considering it was a droughty year. Seedlings from replication 4 are newly planted and their field survival is not reported here. High field survival cannot be fully attributed to carbon dioxide treatment and is probably associated with low root disturbance of container-grown seedlings when out-planted.

Table II. Expected maximum growth at 90 days for seedlings grown in carbon dioxide enriched atmospheres under natural light conditions.

| Growth Measurement | Optimum $CO_2$ Concentration Estimate ± SE | Maximum Growth Estimate ± SE |
|---|---|---|
| | --ppm-- | |
| Total Height | 1115 ± 213 | 268 ± 10 mm |
| Diameter | 924 ± 40 | 4.3 ± 0.1 mm |
| Root Dry Weight | 920 ± 99 | 1.2 ± 0.1 gm |
| Shoot Dry Weight | 1008 ± 102 | 2.0 ± 0.1 gm |
| Total Dry Weight | 979 ± 57 | 3.2 ± 0.1 gm |

Table III. Expected maximum growth at 90 days for seedlings grown in carbon dioxide enriched atmospheres under artificial light conditions.

| Growth Measurement | Optimum $CO_2$ Concentration Estimate ± SE | Maximum Growth Estimate ± SE |
|---|---|---|
| | --ppm-- | |
| Total Height | 1305 ± 424 | 161 ± 11 mm |
| Diameter | 1012 ± 41 | 3.5 ± 0.1 mm |
| Root Dry Weight | 975 ± 47 | 0.8 ± 0.1 gm |
| Shoot Dry Weight | 1109 ± 173 | 1.5 ± 0.1 gm |
| Total Dry Weight | 1050 ± 95 | 2.3 ± 0.2 gm |

Table IV. First year field survival of carbon dioxide treated seedlings.

| Carbon Dioxide Treatment | Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|
| --ppm-- | | --%-- | |
| 175 | 99 A* | 83 A | 80 C |
| 350 | 99 A | 81 A | 87 BC |
| 700 | 100 A | 81 A | 92 AB |
| 1400 | 100 A | 77 A | 98 A |

*Means followed by the same letter are not significantly different ($\alpha = 0.05$) using Duncan's New Multiple Range Test.

## CONCLUSIONS

1. The optimum carbon dioxide concentration for maximum growth of loblolly pine seedlings occurs at approximately 1000 ppm.

2. Predicted growth at the optimum carbon dioxide concentration was 60 percent above that observed in ambient air.

3. Field survival was generally not affected by carbon dioxide enrichment.

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CONTAINERIZED WHITE PINE SEEDLING DEVELOPMENT

FIVE YEARS AFTER OUTPLANTING[1/]

R. L. Hay and J. C. Rennie[2/]

Abstract.--Nursery-grown 2-0 bareroot white pine seedlings and 7 month old containerized seedlings that had received various combinations of extended photoperiod and $CO_2$ enrichment were planted on the Cumberland Plateau in a randomized block design. Total height, stem caliper at the soil surface and biomass of stems and leaves were measured periodically. A cleaning was done after the third growing season.

After five years, the 2-0 seedlings were significantly larger than the containerized seedlings. Of the greenhouse culture treatments, the 24-hour photoperiod had the greatest positive effect on growth while the enriched $CO_2$ treatment depressed growth.

## INTRODUCTION

Eastern white pine (Pinus strobus L) is one of the most important gymnosperms in the East. Within customary market fluctuations, the demand for white pine lumber has been consistent, with prices frequently higher than those for many hardwood species that occupy the same sites. White pine is also popular with Christmas tree growers.

The slow, early growth of white pine seedlings extends time in the nursery required to produce quality plants. In Tennessee, nursery seedlings are dug as 2-0 bareroot stock, but other nurseries might offer 3-0 seedlings or 2-2 transplants. White pine seedlings usually do not develop secondary leaves during the first growing season. The cotyledons are functional until the epicotyl begins to elongate and the primary leaves appear. The primary leaves provide photosynthate throughout the growing season and the overwintering bud develops by late-summer. Seedlings are considered too small for outplanting after only one year in the nursery. During the second year, secondary leaves develop and most seedlings attain sufficient size to survive outplanting.

Container-grown white pine seedlings have several advantages over bareroot nursery stock in certain situations. Quality seedlings can be produced in less than half the time required in a nursery. Seedling bed density can be readily controlled by choosing the appropriate container size. Mycorrhizal inocula of the appropriate fungus can be added to the growing medium. Fertilizer schedule control and minimal insect and disease problems are additional advantages of containerized culture.

The purpose of the study reported here was to test survival and growth of seven month old containerized white pine seedlings compared with two year old, bareroot, nursery-grown seedlings. The plantation was established on Pickett State Forest (Hay and Rennie 1983).

Greenhouse culture techniques for producing the containerized seedlings and the outplanting design were previously reported (Hay 1981; Hay and Keegan 1982; Hay and Rennie 1983). Total height was measured annually. Stem diameter at the root collar was measured for each seedling after year two. Total, above-ground biomass was determined at two, three, and five years, based upon a pre-determined sampling design such that a 10 X 10 residual stem spacing occurred. Stems and leaves were dried at 70C.

Initial site preparation had been effective in minimizing competing vegetation through the second growing season (Keegan 1981). However, by the end of the third growing season, Virginia pine (Pinus virginiana L) wildlings were competing with the experimental white pines. Although it

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was not apparent at this early age what lasting effects the Virginia pine would have on stand composition, a cleaning in which each white pine was released from all woody stem competition was uniformly applied to all plots by cutting all the competing stems. Herbaceous vegetation was not treated.

## SEEDLING PERFORMANCE

### Survival

Survival data were only meaningful prior to sampling for biomass determinations. Mortality of 2-0 bareroot seedlings was greater during the first year than the best containerized seedling treatment (Hay and Rennie 1983). However, by the second year survival was similar for all treatments (Hay and Rennie 1983).

Compared to later outplantings of containerized white pine seedlings on a variety of sites, the survival percentages for containerized seedlings in this study were low. Several factors were involved: the first growing season was hot and dry, the root plug was not well-developed, and the terminal buds failed to elongate immediately after outplanting.

Shortly after the seedlings were planted the weather became unseasonably hot and dry for much of the growing season. Unfortunately this trend continued, intermittently during the entire experiment, with severe drought occurring again during the third growing season. The record-breaking drought of 1985-86 was a continuation of the conditions that occurred during much of the study. Soils on the study site were sandy with low organic matter content and low water holding capacity (Keegan, 1981), further aggravating the drought effects to the seedlings.

Failure of the root plug to remain intact during the planting operation was another problem. A pine bark:sand:vermiculite medium was used in this study and it was so fragile that extreme care had to be used during planting. In subsequent greenhouse tests, which were not a part of this study, a peat:vermiculite medium was used with excellent root plug development. Survival on a variety of sites has been consistently higher in these later outplantings.

Perhaps the greatest problem was the failure of the containerized seedlings to maintain height growth after outplanting because dormancy relationships had been altered during the greenhouse culture phase. Normal daylength during the winter months is not adequate for active terminal elongation so the seedlings received either 24 hour photoperiod or a burst of light each hour of the dark period. When the seedlings were moved to the shadehouse a few weeks prior to outplanting, they received light according to the photoperiod of that early spring season. Apparently some seedlings went dormant in response to the shorter daylength, because many terminals failed to elongate during the first year in the field.

Small trees lacking apical dominance and unable to outgrow increasing competition in the face of impending drought characterized the containerized seedlings after one year in the field. The 2-0 bareroot trees were now three years old, and becoming established.

### Growth Relationships

The 2-0 bareroot seedlings were consistently and significantly larger than any of the containerized seedlings ($\alpha = .05$) throughout the study. They were two years old at outplanting, compared to seven months for the containerized seedlings. The size differences were maintained. See figures 1, 2, and 3.

#### Height Development

Total heights are presented in figure 1. The effects of extending the photoperiod in the greenhouse with a light source designed to promote seedling growth produced significant height growth differences in the second and fifth years after outplanting for the containerized treatments ($\alpha = .05$). The trend was very apparent in the other years as well; individual degree of freedom comparisons were within alpha = .10. The two 24-hour photoperiod treatments produced the tallest containerized seedlings throughout the five years (fig. 1).

When the containerized seedlings were removed from the greenhouse, there were no differences in seedling height according to photoperiod treatments (Hay and Keegan 1982). The height differences in the field that occurred as early as the second year after outplanting were due to seedling responses to environmental stimuli in the field. It's important to note that seedlings grown under 24-hour photoperiod in the greenhouse had significantly higher biomass in both tops and roots after seven months (Hay and Keegan 1982). Height growth in young white pine is largely a function of stored energy and these seedlings appeared better suited for growth in the field than the others even if there were no initial height differences.

Seedlings grown in the carbon dioxide ($CO_2$) enriched atmosphere under natural photoperiod during greenhouse culture were the shortest after five years in the field (fig. 1). The positive effect of 24-hour photoperiod within the $CO_2$-enriched atmosphere somewhat balanced the suppressive effects of $CO_2$, for seedlings receiving light and $CO_2$ were always similar in size to those grown under natural photoperiod without $CO_2$.

Adding $CO_2$ during the greenhouse culture phase significantly depressed ($\alpha = .05$) seedling height growth both in the greenhouse and after outplanting. There is no apparent reason for this, for growing plants in greenhouses in $CO_2$ enriched atmospheres is a long-standing horticultural practice. White pine seedlings have

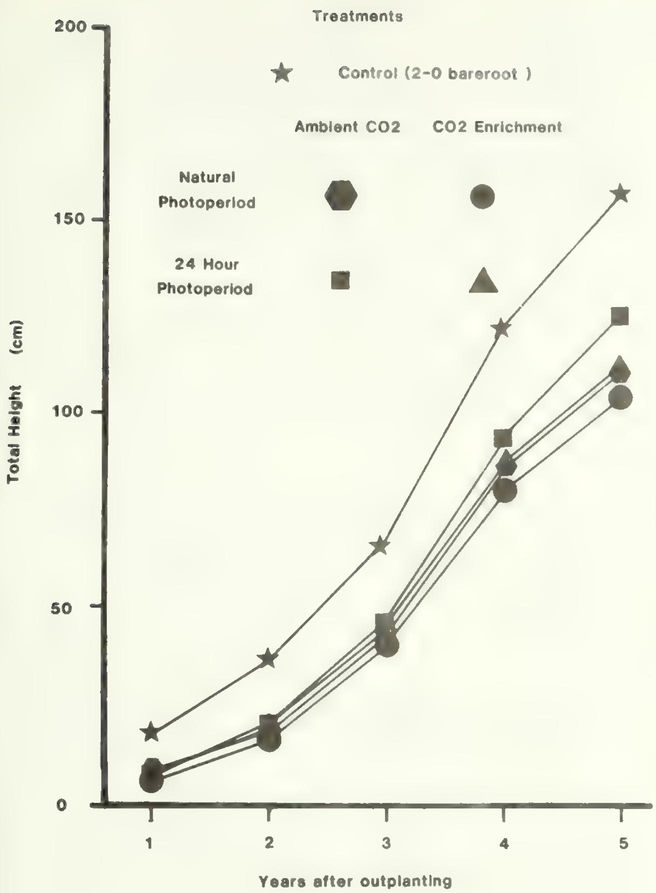


Figure 1.--Total height growth of 2-0 bareroot and 7 month old containerized white pine seedlings through 5 growing seasons on the Cumberland Plateau.

responded positively to 1000 ppm of $CO_2$ (Funsch et al 1970), as have many other species. Yet these seedlings were significantly shortest ($\alpha$ = .05) at outplanting and two years hence with the trend maintained for five years.

Seedling age was a major source of size differences between the 2-0 bareroot and the containerized seedlings. Using seedling age from seed germination and not plantation establishment as the basis for comparisons, the containerized seedlings were similar in total height to the bareroot seedlings (fig. 1). For example, at age four from germination the containerized seedlings averaged 89 cm and the bareroot seedlings were 69 cm tall (fig. 1). The same trend was true throughout the study, but less well defined at the last measurement.

Diameter Growth

Stem diameter growth relationships were similar to those of height development. The 2-0 bareroot seedlings were considerably larger than containerized seedlings at outplanting and they maintained that advantage ($\alpha$ = .05) through the study (fig. 2). Containerized seedling diameter growth after outplanting was influenced by greenhouse culture treatments.

Containerized seedlings grown in the $CO_2$ enriched greenhouse had significantly smaller diameters the second year after outplanting ($\alpha$ = .05). The combination of natural photoperiod and enriched $CO_2$ produced the smallest seedlings. Seedlings from the $CO_2$ greenhouse treatment remained smallest throughout the study, but the differences were not significant at the 5% level.

The 24-hour photoperiod treatment had a positive relationship to diameter growth. Three years after outplanting, the 24-hour photoperiod seedlings were significantly larger ($\alpha$ = .05) than those receiving natural photoperiod. This trend continued throughout the study; the best diameter development occurred for those seedlings receiving 24-hour photoperiod in ambient $CO_2$ atmosphere.

Using age since seed germination for comparisons between the 2-0 bareroot and containerized seedlings had as large or larger diameter than the 2-0 bareroot. Specifically, at year 4 the containerized seedlings were as large as the

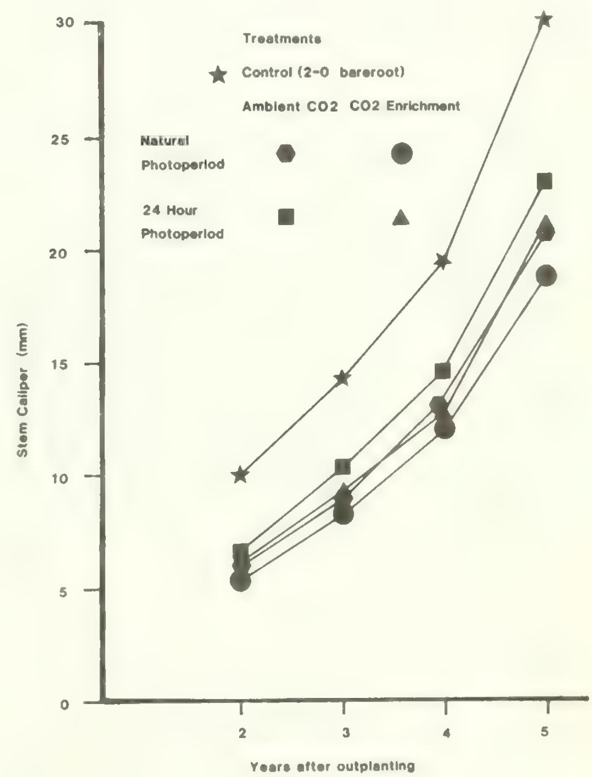


Figure 2.--Stem caliper at the ground for 2-0 bareroot and 7 month old containerized white pine seedlings through 5 growing seasons on the Cumberland Plateau.

2-0 seedlings at year 3 (fig. 2). At year 5 and year 4, respectively, the containerized seedlings had larger diameter.

Diameter growth rate increased the fifth year for all treatments in response to the cleaning which removed crown competition from all treatments. Note the slope changes in figure 2. Most trees responded by expanding crowns beyond what would have been likely if the competing sprouts and Virginia pines had remained. Diameter growth frequently increases after thinnings reduce crown competition in merchantable stands; apparently such responses can also occur in young stands.

Biomass

Biomass estimates were made from seedlings that were harvested at the root collar. Oven-dry weights were analyzed for leaf and stem tissues and total dry weight (fig. 3) for years 2, 3, and 5. The 2-0 bareroot seedlings were significantly larger ($\alpha = .05$) than the containerized seedlings throughout the five years of the study. There were no differences within the containerized seedlings due to greenhouse culture treatments. However, the same trends existed for biomass that have been previously discussed for height and diameter, i.e., the containerized seedlings that were grown in 24-hour photoperiod and ambient $CO_2$ atmospheres were consistently largest and the natural photoperiod plus $CO_2$ enrichment produced the smallest seedlings.

The 2-0 bareroot seedlings appeared to be in a better position than any other treatment to compete favorably on these sites at the termination of the study. The magnitude of biomass differences at year five (fig. 3) indicated that the 2-0 seedlings were well into the rapid growth stage that characterizes sapling-to-pole growth; additional growth increases will likely occur within the next few years. It was uncertain at year five whether the smaller, containerized trees would constitute a portion of the maturing canopy. Without the cleaning prior to year four, there would have been less opportunity for these small trees to have reached dominant canopy position. The larger containerized and the 2-0 bareroot seedlings have a firm position and will soon close canopy over competing species.

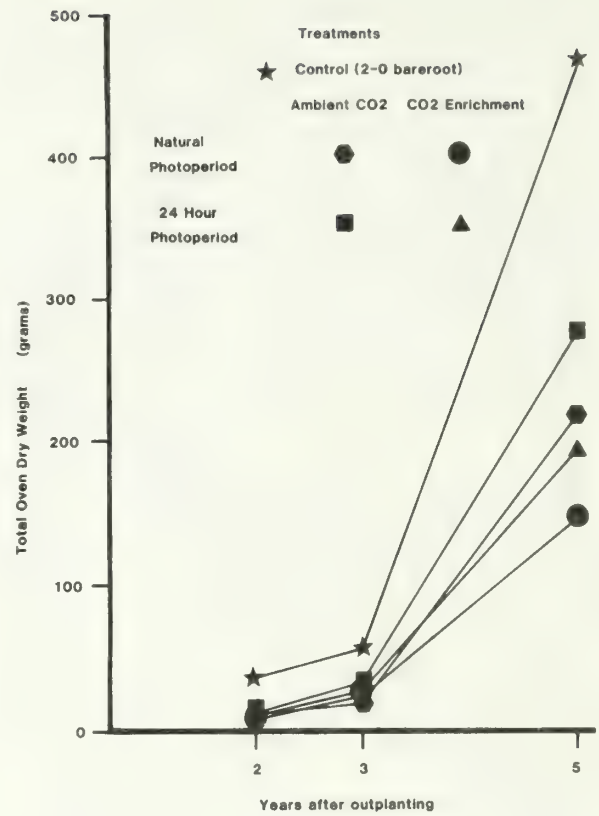


Figure 3.--Above-ground biomass development of 2-0 bareroot and 7 month old containerized white pine seedlings through 5 growing seasons on the Cumberland Plateau.

## DISCUSSION

Based upon the first five years of growth, containerized white pine seedlings did not surpass the 2-0 bareroot nursery stock. The nursery seedlings were larger in all measured variables and by the second year survival was similar. However, there were some extenuating circumstances that were particularly unfavorable toward the containerized seedlings in this test.

The age and related size differences clearly favored the nursery stock which was outplanted as 2-0 bareroot seedlings compared to seven-month old containerized seedlings. However, seedling size based upon age since germination instead of time since outplanting was quite comparable. The containerized seedlings were growing at satisfactory rates, even though they were slow to start growth after outplanting.

Bud dormancy relationships in this study had been altered by the photoperiod treatments during greenhouse culture. In most cases, normal elongation of terminal buds did not occur soon after outplanting. Sometimes the bud remained totally dormant, or some elongated a few centimeters without any leaf development, but most of them lost strong, central stem, apical dominance when one to several sprouts developed from buds at leaf axils. These sprouts supported primary leaves even though secondary leaves had previously existed. New terminal buds formed on the sprouts at the end of the first growing season in the field and normal growth sequences occurred the following spring. For those seedlings with multiple shoots, it was another year before strong apical dominance was re-established.

Since this study was initiated, many changes have been made in our greenhouse culture techniques. Photoperiod treatments are not used past the cotyledon stage and the seedlings go dormant

according to natural photoperiod and temperature stimuli in the autumn after which they can be outplanted as dormant stock or after spring growth has begun. Containerized seedlings at age two are similar in size to 2-0 bareroot nursery stock, but they have already been established in a plantation instead of remaining in the nursery. There are some advantages to such a headstart, if high survival and good growth rates are goals.

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# LONGLEAF PINE SEEDLING STORABILITY AND RESISTANCE TO BROWN-SPOT DISEASE IMPROVED BY ADDING BENOMYL TO THE PACKING MEDIUM[1/]

James P. Barnett and Albert G. Kais[2/]

Abstract: Longleaf pine seedlings planted in January after 1 and 3 weeks of storage with and without benomyl in the packing medium were evaluated for field performance during the following fall. The benomyl-clay mixture improved survival 7 and 60 percentage points over the clay slurry control for the 1- and 3-week storage treatments respectively. Brown-spot occurrence was reduced by 8 percent at both sites following benomyl treatment, although untreated seedlings were only moderately infected with brown-spot needle blight.

Additional Keywords: Pinus palustris Mill., seedling survival, brown-spot disease control, Scirrhia acicola (Dearn.) Siggers

## INTRODUCTION

Recent studies have shown that root-dipping in a clay-benomyl (Benlate®) mixture at the time of planting will provide systemic protection of longleaf pine (Pinus palustris Mill.) seedlings from brown-spot disease (Scirrhia acicola (Dearn.) Siggers) for at least one year in the field (Kais and Barnett 1984, Cordell et al., 1984, Kais et al. 1986a and 1986b). This treatment has improved survival rate and early height growth of the seedlings (Kais 1985, Kais et al. 1986b, Kais and Barnett 1984).

## METHODS

Longleaf pine seedlings from a single seed lot were lifted from nursery beds in southern Mississippi in early January 1985. Seedlings were divided into sublots for two storage periods and for the application of the following five treatments: 1) clay slurry control, 2) clay slurry with a benomyl dip applied at the time of planting, 3) clay slurry mixture with benomyl applied at time of packing, 4) peat-moss control, and 5) peat moss combined with a benomyl treatment. Benomyl was applied in a 10 percent mixture of Benlate® WP50 and kaolinate clay. This resulted in an approximate 5 percent a.i. of benomyl in the clay slurry or dip. A 10 percent dilution of benomyl in water was used as a dip prior to packing with peat moss for treatment 5.

Seedlings were packed in Kraft-polyethylene bags at 350 seedlings per bag and stored at 35° F. The first outplanting was made after 1 week of storage, while the second was made about 3 weeks later. Seedlings were machine planted at a 5-by-5 foot spacing. Four replications of 100 seedlings (2 rows of 50 seedlings) were outplanted for each packing-storage treatment on two different sites in Central Louisiana. The first site was on the Catahoula Ranger District, Kisatchie National Forest. This area had been clear-cut and planted with longleaf pine in 1982, but the planting had been unsuccessful. This site had a moderately high incidence of brown-spot disease inoculum. The second outplanting site was on the Palustris Experimental Forest. This area had been clearcut several years previously and had been routinely burned to reduce woody-plant competition. Brown-spot inoculum was low on this site.

Seedling survival and brown-spot infection were measured in June and December following planting. The December data are reported here. Brown-spot infection was determined by visual estimate of the proportional amount of needle

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tissue that was killed by the disease (Kais 1985, Kais and Barnett 1984, Kais et al. 1986a).

Differences in proportions of survival and brown-spot infection were tested for significance at the 0.05 level by analyses of variance. Duncan's multiple range test was used to evaluate treatment means.

RESULTS

Survival

Outplanting site had considerable effect on longleaf pine seedling survival after one full growing season (table 1). Heavier grass and woody competition as well as greater brown-spot incidence occurred on site 1. Nevertheless, treatment effects followed the same trends on both sites. Both length of seedling storage and packing-medium treatments significantly affected seedling performance. Survival after 3 weeks of storage was markedly lower than after 1 week. The effect of storage varied greatly depending on packing-medium treatments. Storage x packing treatment interactions also significantly affected results at both sites.

The clay-slurry and peat-moss controls had consistently lower survival at 1-week storage than any of the benomyl treatments (table 1). The magnitude of treatment differences was much greater for the 3-week storage treatment. The clay-slurry treatments averaged 19, 33, and 79 percent survival for the control, benomyl dip at planting, and the clay-benomyl slurry, respectively. The peat moss control averaged 64 percent, triple that of the clay-slurry control. The addition of benomyl to the peat-moss treatment improved survival 13 percentage points.

Brown-spot infection

The level of brown-spot infection on seedlings at the end of the first year was higher on site 1 due to a greater amount of inoculum initially present in the soil (table 2). Seedling storage had no effect on occurrence of brown-spot on seedlings at site 1. On site 2, where infection levels were low, significant differences occurred due to lengths of storage.

Statistically significant differences occurred in packing-medium treatments at both sites. Generally, controls had higher infection levels than the counterparts treated with benomyl. On site 1 where the brown-spot levels were higher, the infection rates ranged from 14 to 20 percent (table 2). Benomyl treatment of seedlings reduced these levels to an average of 6 percent.

DISCUSSION

The treatment of longleaf pine bare-root nursery seedlings with benomyl reduced brown-spot infection in the field as had been reported earlier (Kais and Barnett 1984, Kais et al. 1986a). However, perhaps even more important is the improvement in the storability of longleaf pine seedlings. The magnitude of beneficial response due to benomyl treatment is impressive. If these results are typical, the addition of benomyl to the clay slurry packing medium may also be an effective means of improving survival of longleaf pine planting stock. The use of benomyl could be important for overcoming two of the major obstacles to successful artificial regeneration of longleaf pine--low survival and slow initial height growth (Kais 1985).

For the packing medium, it is much easier to incorporate benomyl in a clay slurry than in peat moss. Because most nursery managers now use the clay slurry treatment, this probably will be the preferred method. It is interesting to note that the peat moss control provided considerably higher survival than the clay slurry control. We have no sound explanation for these differences. However, with the addition of benomyl to both treatments, no differences in survival occurred.

Additional studies are being conducted with longleaf pine to confirm these results, to evaluate the response of other pine species, and to determine the mechanisms that may account for these differences.

Table 1.--Survival of longleaf pine seedlings after 1 year in the field[a]

| Treatment | Stored for 1 week: Site 1 | Site 2 | Avg. | Stored for 3 weeks: Site 1 | Site 2 | Avg. |
|---|---|---|---|---|---|---|
| | Percent | | | | | |
| Clay slurry control | 67c | 81a | 74b | 8d | 30d | 19d |
| Clay with benomyl dip | 77abc | 86a | 81ab | 20c | 47c | 33c |
| Clay-benomyl slurry | 79ab | 84a | 81ab | 75a | 83a | 79a |
| Peat moss control | 68bc | 84a | 76ab | 62b | 66b | 64b |
| Peat with benomyl | 81a | 85a | 83a | 74ab | 80a | 77a |

[a] For each column, values with the same letter are not significantly different (0.05 level)

Table 2.--Brown-spot disease infection rates of longleaf pine seedlings after 1 year in the field[a]

| Treatment | Stored 1 week: Site 1 | Site 2 | Avg. | Stored 3 weeks: Site 1 | Site 2 | Avg. |
|---|---|---|---|---|---|---|
| | percent | | | | | |
| Clay slurry control | 19.4a | 3.5a | 11.4a | 19.5a | 5.6a | 12.6a |
| Clay with benomyl dip | 5.9b | 2.4bc | 4.2b | 5.5c | 4.7ab | 5.1c |
| Clay-benomyl slurry | 7.2b | 2.1c | 4.6b | 5.8c | 2.7c | 4.2c |
| Peat moss control | 16.5a | 3.0ab | 9.8a | 14.2b | 4.3d | 9.2b |
| Peat with benomyl | 6.0b | 2.7abc | 4.4b | 4.9c | 3.1c | 4.0c |

a/ For each column, values with the same letter are not significantly different (0.05 level).

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# LATERAL ROOT DEVELOPMENT MAY DEFINE NURSERY SEEDLING QUALITY[1]

P. P. Kormanik and J. L. Ruehle[2]

Abstract.--Commonly used standards for determining the quality of tree seedlings for reforestation do not appear to be good indicators of seedling performance after outplanting. The number of strong lateral roots on a lifted seedling may be an improved indicator. In sweetgum plantings there is strong evidence supporting numbers of strong first-order lateral roots as a grading factor. The percentage of a mother tree's offspring that satisfy this grading criterion appears to be genetically controlled. Frequency distributions for other species indicate a similar situation.

## INTRODUCTION

In this paper we describe a possible new criterion for grading of nursery seedlings for reforestation — the number of first-order lateral roots. Research on the relationship between the number of such roots on a lifted nursery seedling and survival and growth after outplanting is far from complete. At this point, however, we are reasonably certain this criterion will be valuable in grading sweetgum (*Liquidambar styraciflua* L.) seedlings, and we have reason to believe that it will be helpful with other species. This paper outlines some of the evidence that supports the notion of determining seedling quality in part by counting first-order lateral roots. First, however, it presents some evidence that existing grading systems need improvement.

As the popularity of seedling planting for reforestation has increased, the terms "seedling quality" and "quality seedlings" have appeared with greater frequency in the scientific literature. Starting with Wakeley's (1954) groundwork on seedling quality, much research has been done on seedling physiology and morphology as they relate to field performance. Nevertheless, recognizing and defining quality in planting stock is a major issue in forestry today and may be the major cause of regeneration failure in both conifer and hardwood plantations (SIFRC 1984).

For example, Johnson (1984) reported that after northern red oak (*Quercus rubra* L.) seedlings were culled at lifting, fewer than 40 percent were competitive 7 years after outplanting. Boyer and South (1986) recently reported that high mortality is common in southern pine plantations. It is now common practice to overplant loblolly pine (*Pinus taeda* L.) seedlings by 30 percent or more in anticipation of high mortality. Boyer and South also found that over 50 percent of the southern forest tree nurseries they sampled produced fewer than 5 percent grade 1 seedlings based on Wakeley's morphological standards.

Although silviculturists and nurserymen often disagree on the definition of seedling quality, most agree that stock must have enough height to get the top into the sunlight, enough stem diameter to support the top, and enough roots to supply the growing tree with water and nutrients (Bunting 1980). Present nursery technology makes it possible to easily meet standards of height, root collar diameter, and root/shoot ratios, and even to influence root regeneration potential, nonstructural carbohydrate content, and mitotic index of stem apex (Cannell 1985, Duryea 1985, Duryea and Landis 1984, Feret and others 1984 and 1985, Kramer and Rose 1985).

Why then do we still have problems in properly recognizing and defining quality in planting stock? One reason is that often each nursery sets its own standards. Even within a nursery, problems like bad weather cause the standards to be adjusted to meet production quotas. Another reason is procedural convenience. If seedling tops grow too tall, they are often mowed to better meet the size requirements of machinery used for spraying, lifting, and planting in the field. The bags used for packing and storing in certain nurseries will only accommodate seedlings of a certain size, so seedlings that are too large are damaged in packing. From a practical point of view, quality is fitness for purpose, and in the case of forest tree seedlings, fitness means survival and growth after outplanting. We need to develop standards that indicate survival and growth potential and can be understood and employed by nurserymen.

A seedling's quality is difficult to define. Many believe that increasing the size of a seedling improves its quality. Wakeley (1954) stated that seedlings with larger stems were not always of the highest quality and he recognized that physiology should be studied to determine potential quality. Chlorophyll content and nitrogen content

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are useful for research purposes, but analyses of these factors in the operational nursery will probably never be used as a universal index of plant condition. Recent work on root regeneration potential shows it may be a good predictor of the best period to lift conifer seedlings from the nursery (Cannell 1985, Feret and others 1985, Kramer and Rose 1985, Stone 1955, Stone and Schubert 1959, Stone and others 1962 and 1963), but its suitability for determining the quality of individual seedlings is questionable. A seedling might have a high root regeneration potential rating and still be below suitable size standards. Also, root regeneration potential is very difficult for most nurserymen to measure and there is little evidence to suggest this would be useful for hardwoods.

What we need are seedling attributes that will correlate well with performance in the field. The attributes also should be rather easily measured by nursery personnel.

## RESEARCH ON SWEETGUM

Based on the results of some earlier mycorrhizal research at the Institute for Mycorrhizal Research and Development we began to see the need for correlating individual seedling attributes — rather than groups of seedlings sharing broadly defined attributes in common — with field performance. In 1974 a major research initiative at the Institute was designed to improve morphological seedling quality of sweetgum seedlings using selected vesicular-arbuscular mycorrhizal (VAM) fungi and appropriate fertilizers in the nursery. At first we found that seedling size could be significantly improved in 80 to 90 percent of the seedlings by maintaining adequate levels of viable VAM inoculum and moderate levels (25 to 50 ppm) of available soil phosphorus (Kormanik and others 1977 and 1981). Later we discovered that more than 90 percent of the progeny from most half-sib mother trees exceeded the seedling size minimum (0.6 to 0.9 cm root-collar diameter and >0.6 m stem height) when available soil P was maintained at high levels (75 to 150 ppm) regardless of VAM inoculum levels (Kormanik 1985).

When these seedlings of uniform size, all above the size minimum, were outplanted, some individuals grew rapidly and expressed dominance after 5 years while others grew poorly. When roots were excavated during the first growing season and assessed for mycorrhizal development, growth differences between individual seedlings could not be attributed to differences in mycorrhizal or other nursery treatments (Kormanik 1985). These assays showed that the roots of all seedlings throughout the plantations were well colonized by indigenous VAM fungi several months after planting. However, additional root excavations in subsequent years indicated a positive correlation between growth performance and number of first-order lateral roots. These field observations did not allow us to separate cause from effect, but they suggested that the number of first-order lateral roots formed in the nursery might be a key to determining a seedling's quality. For this work, strong laterals in sweetgum were defined as roots that are suberized to some degree, are larger than 1 mm in diameter at the proximal end, and occur within 15 to 25 cm of the root collar.

Research was initiated to determine if nursery practices had an effect on the frequency of these lateral roots. Studies were conducted for several years at the Whitehall microplot nursery in Athens employing combinations of cultural procedures, fertility, and symbiont inoculation. Over a 3-year period thousands of seedlings were grown under many treatment combinations; a few combinations resulted in 80 to 90 percent of the seedlings from any half-sib seedlot exceeding the minimum size standards mentioned above. However, regardless of treatment combination or seedling size, the numbers of seedlings in first-order lateral root classes was comparable. The frequency distribution of seedlings rated on number of first-order lateral roots remained rather constant within each seedlot, regardless of nursery treatment, with from 30 to 50 percent, depending on seedlot, having fewer than four strong, first-order lateral roots. Previous field data showed that seedlings in this root category survived and grew poorly. We then assessed seedlings from both state and industrial nurseries using other seed sources and found similar frequency distributions. It appeared to us that this root characteristic was under genetic and not cultural control. Kormanik and Muse (1986) proposed that regardless of the phenotypic characteristics of a mother tree, seedlings from this tree will exhibit a range in the frequency distribution of first-order lateral roots. They further suggested that seedlings with less than four strong, first-order lateral roots will be significantly less competitive in a plantation.

Seedlings from recent nursery studies involving the above mentioned treatment combinations were lifted, individually assessed, and outplanted on an upland site near Aiken, South Carolina. Early field results have been reported by Kormanik (1986). The 5,000 planted seedlings were grown under a wide range of fertility regimes, with or without mycorrhizae. Approximately 50 percent had less than four strong, first-order lateral roots. Seedlings were planted at 3.3 x 3.3 m spacing and each subplot contained trees with similar root morphology.

After 1 year in the field, nursery treatments had little influence on survival and growth. However, in spite of a record drought during this year, 80 percent of the seedlings within each subplot with more than six strong, first-order lateral roots survived. During the fourth growing season, seedlings in these subplots were clearly superior. Their crowns had closed and were more than twice as large as surviving seedlings on subplots established from seedlings with less than four first-order lateral roots.

This work with sweetgum strongly suggests that field performance can be greatly improved by planting only seedlings exceeding the minimum aboveground standards and having more than five strong, first-order lateral roots. If such

standards are employed, from 30 to 40 percent of the annual crop in most nurseries will have to be culled. Although our field data only covers 4 years of growth, if these early growth differences continue for another 3 to 6 years, the expense of culling should be easily justified.

Since results with sweetgum research were so promising, we decided to examine seedlings of other important forest trees. We used the same standards for rating strong, first-order lateral roots realizing that the 1 mm diameter minimum might be inappropriate for other tree species. This lower limit may be too low for walnut and oak and may be too large for southern pines. Future research on outplanting performance should provide the appropriate adjustments for these other species.

## OBSERVATIONS ON OTHER SPECIES

In addition to sweetgum we have estimates of first-order lateral root counts on walnut (*Juglans nigra* L.), northern red oak, green ash (*Fraxinus pennsylvanica* Marsh), loblolly, and longleaf (*Pinus palustris* Mill.) pines (Table 1). Although we realize that extensive research is needed before a seedling's quality can be defined for each of these species, we saw some interesting relationships after making these assessments. By combining minimum seedling size and counts of lateral roots we estimated that more than 60 percent of the walnut and northern red oak should be culled. This is in agreement with the results reported by Johnson (1984) from a 7-year field study with northern red oak.

In our nursery studies on pine and oak, fertilization adjustments to make seedlings larger had little effect on numbers of strong, first-order lateral roots. However, if seedlings were grown at high seedbed densities, it became difficult to identify strong, first-order lateral roots. As seedbed density increased the first-order laterals tended to be smaller in diameter and had less secondary thickening. We feel that this response is directly related to the fact that less photosynthetic capacity is exposed to optimal light intensity at these higher densities.

If, as we suspect, a seedling's development of strong, first-order lateral roots is under strong genetic control, then nursery practices should be adjusted to permit this trait to be fully

Table 1.--Frequency distribution of seedlings having strong, first-order lateral roots exceeding 1 mm in diameter at proximal end

| Number of first-order lateral roots | Sweetgum | Walnut | Northern red oak | Green ash | Loblolly pine | Longleaf pine |
|---|---|---|---|---|---|---|
| 0 | 5 | 0 | 42 | 67 | 12 | 39 |
| 1 | 521 | 107 | 33 | 34 | 46 | 83 |
| 2 | 468 | 37 | 50 | 37 | 129 | 100 |
| 3 | 697 | 29 | 56 | 33 | 198 | 139 |
| 4 | 439 | 24 | 55 | 41 | 197 | 140 |
| 5 | 410 | 31 | 56 | 27 | 233 | 149 |
| 6 | 371 | 20 | 41 | 37 | 230 | 140 |
| 7 | 237 | 27 | 44 | 18 | 210 | 111 |
| 8 | 199 | 13 | 48 | 19 | 217 | 109 |
| 9 | 135 | 21 | 35 | 14 | 169 | 99 |
| 10 | 107 | 10 | 42 | 14 | 116 | 96 |
| 11 | 79 | 7 | 26 | 10 | 85 | 55 |
| 12 | 51 | 11 | 37 | 7 | 58 | 35 |
| 13 | 38 | 6 | 31 | 4 | 49 | 36 |
| 14 | 37 | 9 | 26 | 6 | 29 | 27 |
| 15 | 19 | 2 | 35 | 2 | 19 | 23 |
| 16 | 7 | 5 | 29 | 4 | 6 | 25 |
| 17 | 9 | 9 | 10 | 1 | 2 | 9 |
| 18 | 3 | 3 | 8 | 1 | 1 | 8 |
| 19 | 2 | 3 | 9 | 1 | 1 | 6 |
| 20 | 2 | 1 | 10 | | | 3 |
| 21 | 1 | 2 | 6 | | | 1 |
| 22 | 1 | 1 | 2 | | | |
| =>23 | 2 | 1 | 15 | | | |
| Total No. seedlings | 3840 | 379 | 746 | 377 | 2010 | 1433 |

expressed. This is particularly important if seedlings are to be culled at lifting for 1-0 stock, or before lining out in the case of 1-1. If nursery personnel, in addition to assessing height and stem diameter, must identify strong, first-order lateral roots, the roots should be fully developed to maximum size and show secondary thickening.

## CONCLUSION

Extensive nursery and field research will be required to determine the appropriate combination of stem and root characteristics for each individual tree species because growth and development of seedlings varies by species, nursery location and environmental conditions. Each species tested may require different combinations of height, stem diameter and number of strong, first-order lateral roots to define a seedling's quality. Our experience during the past 8 years in nursery experiments with sweetgum, oak, walnut, and pine seedlings found that with selected nursery treatments, there were often many seedlings with large stems and few strong, first-order lateral roots, and with other treatments, there were many seedlings with short, spindly stems also with few laterals. But we have never observed seedlings in any treatment with many strong, first-order lateral roots and short, spindly stems.

We have found, within a reasonable range of nursery conditions, lateral root development remains rather stable. We suggest that because of the predictable frequency distribution of pine and hardwood seedlings derived from counts of strong, first-order lateral roots within half-sib progeny, lateral root morphology should provide a biological basis for assessing a seedling's quality.

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# A 15 DAY HYDROPONIC SYSTEM FOR MEASURING ROOT GROWTH POTENTIAL: MEASUREMENT AND SAMPLE SIZE FOR LOBLOLLY PINE [1/]

By Robert C. Freyman and Peter P. Feret[2/]

Abstract— The 15 day hydroponic system has proven to be a simple, inexpensive, and relatively fast method for measuring root growth potential (RGP). This paper describes various measures of RGP. It appears that while new root length is a better predictor of field growth performance than new root number, correlations between new root number and growth increment can be made to approach those of root length by using only number of long roots. Compared to new root number or length, percent seedlings producing 1 or more new roots is better correlated with survival. Data are presented for sample sizes to estimate a particular mean at precision levels of ± 10%, ± 20%, and ± 30%.

## INTRODUCTION

The realization that a seedling should be evaluated by more than morphological criteria has generated interest in measuring seedling physiological quality. Root growth potential (RGP), defined as the ability of a tree seedling to quickly produce and elongate new roots in an environment favorable for root growth, is being used as an indicator of seedling quality. RGP maybe one of the more reliable predictors of field performance (Ritchie, 1985).

Nurserymen have control over seedling morphology through the application of cultural practices such as sizing seed, sowing rate, irrigation, fertilization, top pruning, under-cutting and wrenching. Cultural practices also affect the quality of the crop produced. Morphological grades may indicate seedling quality but within a given morphological grade, physiological quality can vary greatly and the relationship between RGP and seedling size has been shown to be weak. Feret and Kreh (1985) found no relationship between loblolly pine seedling RGP and root collar diameter and Feret et al. (1985a) found less than twenty percent of 128 seedling samples showing a relationship between RGP and loblolly pine seedling height, root collar diameter, volume index ($D^2$ x H), or height/diameter. Larsen and Boyer (1985) found some relationship between RGP and seedling morphology in a study of seedlings from twenty nurseries, but concluded that "a significant and probably greater degree of variation in RGP can exist among seedlings of similar morphology."

While nurserymen have control over seedling morphology, they can also control factors affecting physiological quality but not morphology; these factors include seed source (Ritchie, 1985; DeWald, et al. 1985b), time of lift (DeWald, 1986; Freyman and Feret, 1986; Feret et al., 1985a) and cold storage condition and duration (Barden and Feret, 1986; DeWald, 1986; Carlson, 1985; Feret et al., 1985b). Nurserymen, who routinely check the size, form, and color of their crop during the growing season should also consider checking the physiological condition of their crop during the lifting season, and after handling and storage.

The lifting season is an extremely busy period during the nursery year. Any method for monitoring seedling quality changes must be easy and inexpensive. The usual RGP test involves placing seedlings in a soil medium and after a three to four week period removing the seedlings and evaluating RGP in some manner. Ritchie (1985) described the typical soil system, alternatives, and RGP testing in general. There are many disadvantages to the four week soil testing system. These disadvantages and an alternative hydroponic system have been described by DeWald et al. (1985a). The hydroponic system is easy and inexpensive to build and operate. The hydroponic system also produces results equivalent to those of the soil system but in a shorter time period (DeWald et al., 1985a). (Ritchie, 1985 also presented results showing good correlation between a hydroponic system and a soil system.) Briefly, the hydroponic system consists of placing

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seedlings in aerated 37.8 liter (10 gallon) aquariums for a full 15 days after which seedlings are evaluated for RGP.

This paper further describes the use of the hydroponic system presented by DeWald et al., 1985a, those RGP measures which maybe of most interest, the nature of the data taken, the type of variability that can be expected, and appropriate sample sizes for a given level of RGP measurement precision.

## RESULTS AND DISCUSSION

### ROOT GROWTH POTENTIAL MEASURES

Though the hydroponic system provides RGP results cheaper and quicker than the soil system, RGP measurement is still more involved than just taking morphological measures. A growing body of data is showing that RGP is a good indicator of loblolly pine field performance and is worth the trouble to measure. The correlations in table 1 show the significant relationship between RGP and loblolly pine first year survival and growth, especially for those samples planted in the spring when conditions allow expression of RGP. Significant correlations between RGP as number of new roots and loblolly pine seedling field performance have also been shown by Feret and Kreh (1985) (.63 and .69 for first year survival and height increment for 31 sample means), Feret et al. (1985a) (.42 and .44 for first year survival and height increment using 44 sample means), DeWald et al. (1985b) (0.76 for first year height increment using 15 sample means, survival was uniformly $\geq$ 95%), and Barden (1986) (0.52 and 0.80 for first year survival and height increment using 50 sample means).

Ritchie (1985) described various measures of RGP, including counting the number of roots, measuring the length of the new roots, using water displacement difference of the root system before and after the test, and weighing the new roots. Of the above methods, counting and measuring length of the the new roots are probably the most common and need no special equipment. We usually assess the new root system by dividing it up into short roots (those that are greater than 0.5 cm but less than 1.5 cm), and long roots (those that are greater than 1.5 cm in length). RGP is calculated as either:

1. number of new roots = number of shorts + number of long roots. or:
2. length of new roots = number of shorts + length of long roots. (Number of short roots = length of short roots because short roots are essentially 1 cm in length.) In general, field performance is better correlated with length of new roots as compared with number of new roots, but measuring the length of the new roots can be a very tedious and time consuming process. Counting the number of new roots is faster and easier. Because the only difference between number of new roots and length of new roots is in either counting the long roots or measuring the long roots, the relationship between length of long roots and number of long roots was determined.

Table 1. Loblolly pine seedling root growth potential - field performance correlation coefficients for all samples and spring lifted samples[1]

| | All Samples (n=64) | | | | |
|---|---|---|---|---|---|
| | 1st yr ht.inc. | 2nd yr ht.inc | 3rd yr ht.inc. | 1st & 2nd yr BA inc. | 3rd yr BA inc. |
| number of new roots | 0.39** | 0.16 | 0.15 | 0.40** | 0.21 |
| length of new roots | 0.30* | 0.11 | 0.15 | 0.42** | 0.30* |

| | Spring Lifted and Planted Samples (n=16) | | | | |
|---|---|---|---|---|---|
| | 1st yr ht.inc. | 2nd yr ht.inc. | 3rd yr ht.inc. | 1st & 2nd yr BA inc. | 3rd yr BA inc. |
| number of new roots | 0.77** | 0.53* | -0.04 | 0.51* | 0.16 |
| length of new roots | 0.66** | 0.33 | -0.12 | 0.52* | 0.16 |

1. Data from an unpublished root growth potential genetics experiment of Feret, P.P. and R.E. Kreh, Dept. of Forestry, Virginia Polytechnic and State University, Blacksburg, VA.

* Significant at the .05 level.

** Significant at the .01 level.

total length long roots = 1.87 + 4.31 number of long roots

$$n=4741 \quad r^2 = .77$$

The above equation (based on seedlings from the soil system) indicates that a weighted count, i.e. weighting the number of long roots by a factor of about 4 and adding that to the number of short roots should produce a quantity equivalent to new root length.

In order to determine if correlations between field performance and number of roots could be improved, field data from a 1983 outplanting established on an old field on the Virginia Piedmont were reinvestigated. These data are presented in table 2. First, one should note that RGP, however it is measured or transformed, is closely correlated with first year and second year field performance. RGP is expected to be correlated with first year field performance, but it is interesting that second year growth is also indicated by RGP. The data in table 1 also show significant second year performance correlations (for spring planted seedlings) but the correlations are weaker compared to the first year correlations. Third year increment is not correlated at all with planting time RGP (table 1).

Two basic criteria evaluate field performance, the first being survival and the second being growth. Height and basal area growth data in table 2 show that sample means of new root length correlate better than do means of number of new roots, and much better than median number of new roots. Weighting the number of long roots however, produces correlations approaching those produced with root length. Weightings of 4 or 10 (ie. total number = number of shorts + number of longs * 4) produce correlations with growth increment equivalent to those of root length. This indicates that the long roots are more important than the short roots in contributing to the association between number of new roots and growth increment. In fact correlations between growth increment and just number of long roots are better than total number of roots and as good as length of roots.

Average number and length of new roots produce slightly lower corrrelations with survival as compared with growth. This can be noted in table 1 and 2 and the correlations cited above. If the RGP sample is evakyated by using the percentage of the seedlings in a sample producing one or more new roots, better correlations can be obtained. For example a correlation of 0.64 is obtained between first year survival and the percentage

Table 2. Loblolly pine seedling root growth potential - field performance correlation coefficients.[1] Comparison of RGP measures.

| | 1st yr[2] ht.inc. | 2nd yr ht.inc. | 1st yr[3] BA inc. | 2nd yr BA inc. | 1st yr survival | 2nd yr survival |
|---|---|---|---|---|---|---|
| MEAN new root LENGTH | 0.55 | 0.57 | 0.56 | 0.61 | 0.47 | 0.48 |
| MEAN new root NUMBER | 0.50 | 0.51 | 0.53 | 0.55 | 0.48 | 0.48 |
| MEDIAN new root NUMBER | 0.42 | 0.46 | 0.46 | 0.48 | 0.42 | 0.42 |
| NUMBER[4] (long*4) | 0.53 | 0.54 | 0.57 | 0.60 | 0.47 | 0.47 |
| NUMBER (long*10) | 0.54 | 0.55 | 0.57 | 0.61 | 0.46 | 0.46 |
| NUMBER (long only) | 0.53 | 0.55 | 0.57 | 0.61 | 0.44 | 0.45 |
| smpl% $\geq$ 1[5] new roots | 0.46 | 0.51 | 0.49 | 0.52 | 0.64 | 0.62 |

1. Combined data from outplantings associated with experiments reported by Feret et al. (1985a) and Feret et al. (1985b). n=56 for first year growth increment, n=54 for second year growth increment, n=62 for survival. All correlations are significant at the 0.05 level.
2. Height increment.
3. Basal area increment.
4. Mean number of new roots, number of long roots weighted as indicated and added to short roots.
5. Percent of the RGP sample which produced greater than or equal to one new root.

of the seedling sample producing 1 or more new roots (that is, showed any new root growth at all) compared to a 0.48 correlation with number of new roots.

The above indicates that RGP is related differently to survival as compared to growth. Survival is computed on all seedlings, while growth is computed only on living seedlings. Survival and growth are also different quantities, in that survival is qualitative measure, while growth is quantitative. In order for a seedling to survive it needs a minimum of whatever attributes are critical for the seedling in the planting situation presented. If the seedling possesses the needed attributes in proper measure, it will survive, with no way to distinguish it from another seedling which possess the same attributes, but in greater measure. However, with growth, one would expect that those seedlings with a greater measure of the necessary attributes will grow more compared to seedlings with a lesser measure of the necessary attributes. Figure 1 shows that survival has a nonlinear relationship with number of new roots, while growth has a more linear relationship with a number of new roots. Percent good seedlings, in contrast, is better correlated to survival than new root number, and more linearly related. This relationship between survival and RGP can be seen in Feret and Kreh (1985) Beineke and Perry (1965) with slash pine and in lodgepole pine (Burdett et al., 1983). That is,

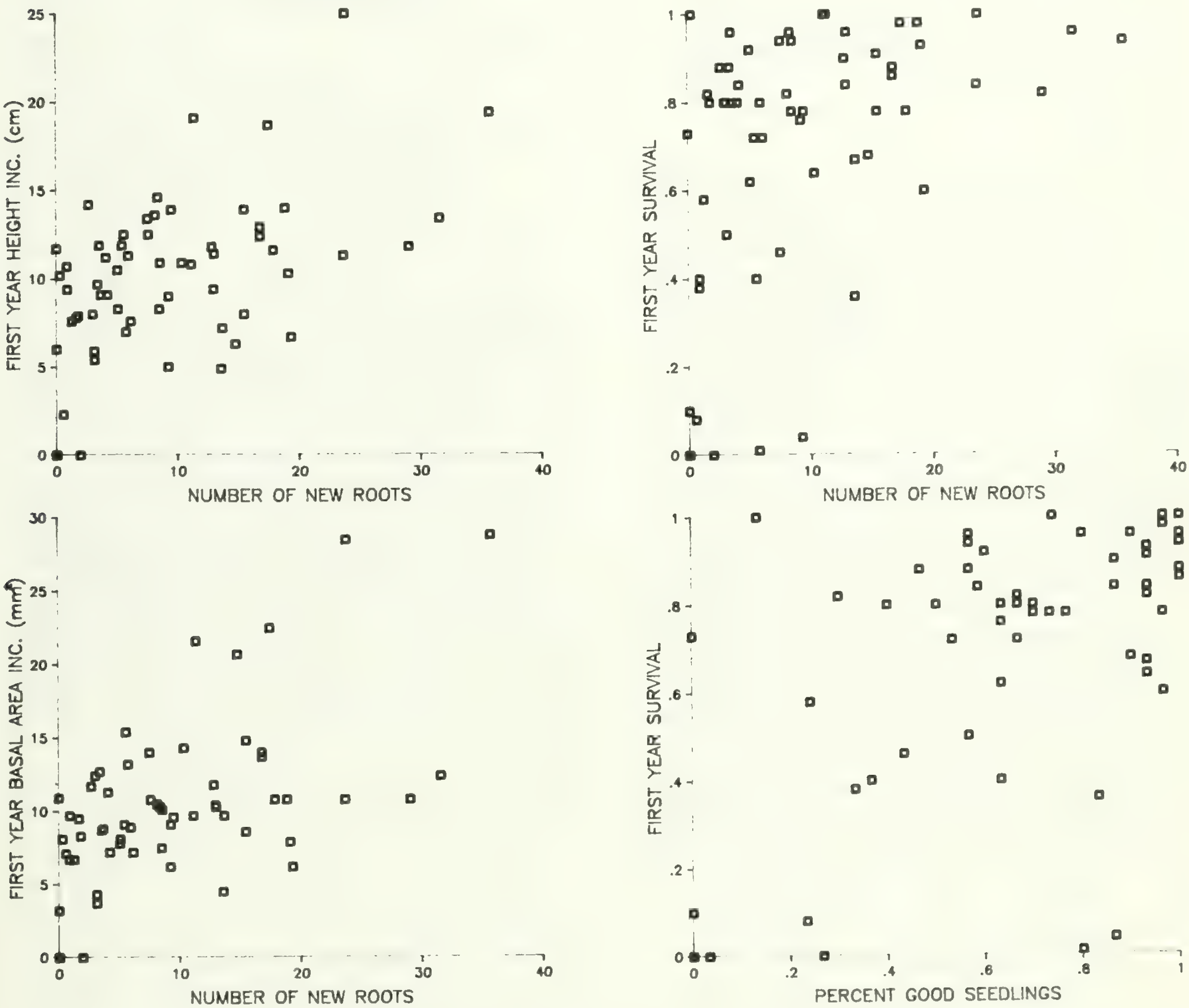


Figure 1. Relationship between loblolly pine field performance and root growth potential as number of new roots or percent good seedlings

at lower RGP a greater proportion of a sample is composed of seedlings that do not possess the needed attributes in proper measure for survival, and while poor survival may not always occur, greater variability in survival can be expected. Once a suitable RGP is attained there is little increase in survival. It appears from the correlation coefficients in table 2 that the percent of the sample producing at least one or more new roots is the best indicator of the proportion of the seedling lot which will have the necessary attributes in proper measure to survive. In almost any given sample a proportion of the seedlings will survive, but these surviving seedlings will most likely show growth in direct proportion to the average RGP of the sample. Therefore, two measures of RGP are of interest, the first being the percentage of seedlings in a sample producing at least some new roots (being the best indicator of survival), and second, the average number of new roots (indicating the expected growth relative to that of other samples).

SAMPLE SIZES

If RGP is to be used to monitor the changes that occur in a seedling crop during the lifting season and/or cold storage, an appropriate sample size must be taken to determine RGP with a certain precision and confidence. Before determining sample size a few comments about the data are needed. The following discussion is concerned with individual trees as replications. In the hydroponic system seedlings from any given sample are placed in more than one tank. These tanks are not considered the replication. It has been our experience that tank does not affect RGP. Even if tank in the hydroponic sys-system did affect RGP, the amount of variation would have to be fairly large to consider it in any analysis. The loss in efficiency of going from single tree replication to tank replication would most likely out-weigh any reduction in variance by including tank in the model.

Using number of new roots as the measure of RGP provides count-type data. This type of data is commonly not normally distributed. Taking the square root of the individual seedling observations usually normalizes the data nicely. Any statistical analysis should be preformed on transformed data.

Figure 2 shows the typical variation that is encountered with the hydroponic system. Two things are of interest to note in the figure. First, the x-axis shows the typical range in sample averages for number of new roots after the 15 day hydroponic test. Second, the trend in coefficient of variation is seen to stabilize in samples with averages greater than about 2 new roots. At very low sample averages the CV's are very high due to the large number of seedlings with zero RGP. Average CV in samples that have averages greater than 2 new roots is 85% in the raw form and 55% after transformation by square root.

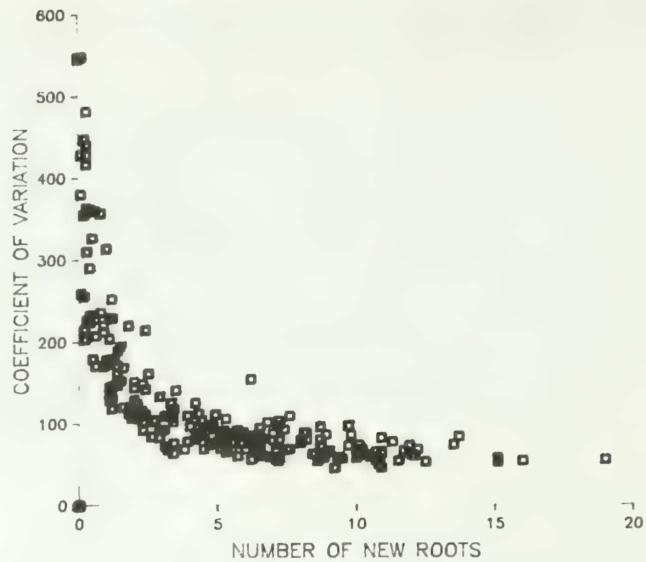


Figure 2. Relationship between coefficient of variation and root growth potential as number of new roots for loblolly pine seedlings from the hydroponic system.

There are two different situations in which sample size is important. First, one may want to determine with precision and confidence a particular mean RGP, or, one may want to determine if two sample means are different. An example of the first situation would be a nurseryman monitoring the RGP changes that occur over a lifting season. At any particular period the average RGP of the seedling crop would need to be esti-with a certain precision (ie. $\pm$ 20%) at a particular confidence level (perhaps 95% confidence). As an example of the second situation, a nurseryman may desire to know if the RGP is statistically different between two areas of the nursery, or perhaps between two months during the lifting season. In this situation he would need to know the particular sample size needed to differentiate two means that are, perhaps 30% or more different, 80% of the time at the 0.05% significance level. In the first case sample size calculations need to be based on the raw data. In the second case transformed data should be used.

Sample sizes for the first situation (determining a particular sample mean) for hydroponic and soil systems were determined in two ways. First, sample size was estimated from each sample with an average of $\geq$ 2 new roots (these were considered to have "stable" CV's). There were 172 and 157 samples that had sample means of at least 2 new roots in the hydroponic and soil systems respectively (table 3). The sample sizes that were estimated from each of these individual samples were averaged to give an overall estimated sample size for three precision levels all at 95% confidence. Sample

Table 3. Estimated sample sizes for the hydroponic and soil RGP systems using individual RGP samples for estimation - method 1 (all samples had mean RGP $\geq$ 2 new roots) or, using one population of seedlings - method 2. (Estimated at 95% confidence level).

| | $N^1$ | Number[2] | Sample Size[3] (raw data) $\pm$10% | $\pm$20% | $\pm$30% |
|---|---|---|---|---|---|
| Hydroponic (method 1) | 172 | 6.3 | 351 | 88 | 39 |
| Soil (method 1) | 157 | 10.9 | 524 | 131 | 58 |
| Hydroponic (method 2) | 8827 | 4.8 | 638 | 159 | 71 |
| Soil (method 2) | 5830 | 8.9 | 747 | 187 | 83 |

1. Number of samples (for method 1) or seedlings (for method 2) from which sample sizes were calculated.
2. Mean number of new roots of the samples used to estimate sample size.
3. Estimated sample size at three levels of precision using raw data.

size was also estimated by placing all seedlings from all samples into one large population. There were 8827 and 5830 seedlings in the hydroponic and soil populations respectively. Table 3 presents the estimated sample sizes needed for three precision levels at 95% confidence. In general estimated sample sizes are smaller for the hydroponic system as opposed to the soil system and samples estimated by the second method are larger than the first method. Two factors need to be balanced in deciding on sample size, level of precision and practical sample size. To be within $\pm$ 10% a sample of 300 to 600 seedlings would be needed. That is too large. If one considers a sample of 45-60 seedlings as manageable, then one can expect a range of about $\pm$ 30% of the sample mean will include the true mean 95% of the time.

Sample size estimation in the second situation of determining the difference between two means depends in part on the number of treatments in the analysis (or the number of degrees of freedom for error estimation), the desired probability of being correct (the power of the test) and the significance level for the statistical test. Transformed data should be used in order to fulfill the assumptions of the test and to make the test more sensitive. Table 4 presents an example approximating a typical situation. It appears that with a sample size of 45-60 seedlings, a difference of about 30% between two means will be detected 80% of the time at the 0.05 significance level (compared to a 50% difference in the raw data).

Table 4. Approximate detectable difference between two means

$$n = 2\,(CV/\%difference)^2 \times (t_{0.05} + t_{2(1-P)})^2$$

or

$$\%difference = ((2)(CV)^2(t_{0.05} + t_{2(1-P)})^2)/n$$

n= sample size, CV= coefficient of variation, % difference = percent difference between two means, P = desired probability that a difference will be found, t = values from two tailed t-table. (Sokal and Rohlf, 1981)

assume P= 80% probability of being correct at 0.05 level of significance using infinite t values.

| sample size | % difference: raw data (CV=85%) | transformed (CV=55%) |
|---|---|---|
| 30 | 62 | 40 |
| 45 | 50 | 32 |
| 60 | 43 | 28 |

The above discussion is centered on estimating the average number of new roots. Estimating the percentage of a sample which produces new roots will take larger sample sizes (estimated at about 300-500 seedlings to be within $\pm$ 30%). However evaluating the number of seedlings which show some RGP or no RGP will be very rapid and if ninety seedlings are placed in one tank, only six tanks will be needed.

## CONCLUSIONS

The fifteen day hydroponic test (as described by DeWald et al., 1985a) is a cheaper, faster, and simpler alternative to the standard soil system for evaluating RGP. Two measures are of primary interest, the first being the average number of new roots which is the best indicator of growth in the field, and the second being the percentage of the seedling sample which produce at least 1 new root which best indicates field survival. Sample sizes of 45-60 seedlings, using individual seedlings as replication, will provide precision of about $\pm$ 30% and delineate two means that are about 30% different in the transformed scale using the square root transformation.

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# ROOT GROWTH POTENTIAL AND OUTPLANTING PERFORMANCE OF LOBLOLLY PINE SEEDLINGS RAISED AT 2 NURSERIES[1/]

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Loblolly pine (Pinus taeda L.) seedlings from 5 seedlots (4 half-sib and a seed orchard mix) were raised at the Virginia Division of Forestry nursery at Providence Forge, Virginia, and at the Westvaco Corporation nursery in Summerville, South Carolina. Seedlings were lifted every 2 weeks, from late October 1984 until mid-February 1985, and their root growth potential (RGP) determined. In addition, seedlings were stored from the February lift and outplanted at 3 week intervals in the Virginia Piedmont from early March until late May 1985. RGP was determined on stored seedlings after each planting date. RGP varied by nursery, seedlot, and lift date, and all first-order interactions were significant. First year survival was significantly correlated with RGP.

## INTRODUCTION AND OBJECTIVES

The decreasing survival of planted loblolly pine (Pinus taeda L.) seedlings is a major concern in the South. In their survey conducted from 1960 to 1978, Weaver et al. (1980) reported that pine plantation survival had decreased, while the acreage planted had nearly doubled. It has been estimated that 30% of planted seedlings die, and that much of this mortality is due to poor stock quality and improper handing procedures (Venator 1981). Since over 1 billion bareroot seedlings are planted yearly in the South (Boyer and South 1984, Johnson et al. 1982), high mortality represents a substantial loss.

During routine lifting operations, a seedling typically loses 75% of its root mass (Nambiar 1980). During operational root pruning to a 14 cm (5 1/2") taproot, the seedling's absorptive surface is further reduced. The size of a seedling's root system may not be critical for growth in the nursery bed, due to being well supplied with water and nutrients in that environment (Nambiar 1980). However, after being lifted and losing most of its roots, a seedling is planted in the field and subjected to moisture stress and low levels of available nutrients. As a result, initial survival of outplanted seedlings depends to a large extent on the ability of the injured root system to rapidly grow and re-establish intimate contact with the soil (Kozlowski and Scholtes 1948).

Root growth potential (RGP) is the ability of a seedling to regenerate its root system after planting in a controlled environment. Stone (1955) developed the procedure which has become the standard method for RGP determination. This procedure involves sampling seedlings, removing any new white roots, pruning the taproots to a specified length, and placing the seedlings in a controlled environment for a set period of days. At the conclusion of this period the new root growth is quantified.

RGP has been demonstrated to be positively correlated with survival and/or field performance in Pinus spp. (Feret et al. 1985a and b, Feret and Kreh 1985, Sutton 1980, Burdett 1979, Stone and Norberg 1979, Jenkinson 1978, Rhea 1977, Stone 1955). In loblolly pine, as RGP levels increase, survival and first year height increment also increase (DeWald et al. 1985b, Feret and Kreh 1985, Feret et al. 1985a and b; 1984).

RGP has been successful in assessing the onset of seedling dormancy, and its relationship to lifting dates, storage effects, and field performance (DeWald et al. 1985a, Feret et al. 1985b, Jenkinson 1980, Stone and Jenkinson 1971). The expression of RGP also has a strong genetic component. DeWald et al. (1985b) and Carlson (1985) both have shown significant differences in RGP between half-sib loblolly pine families.

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Kramer and Rose (1985) noted a thorough evaluation of seasonal and genetic variation of southern pine RGP was needed, and concluded that progress towards improving and standardizing seedling quality would be accomplished through a better understanding of how RGP variation is related to shoot dormancy. DeWald's (1986) recent work has provided much needed information in this area. Further work on the RGP of loblolly pine seedlings will result in more efficient manipulation of seedling physiology, resulting in seedlings with greater survival and growth potential.

With these considerations in mind, the objectives of this study were twofold:

1. Quantify root growth potential changes during the lifting season over 2 nurseries and 5 seedlots (Experiment I);

2. Determine the relationship between RGP and subsequent outplanting performance after cold storage (Experiment II).

## METHODS AND MATERIALS

### Seedling Culture

Seed sources for the study were 4 half-sib families and a seed orchard mix. All seed lots originated from the Westvaco Virginia Piedmont source seed orchard in Summerville, South Carolina. Seed was hand sown in April 1984 at the Virginia Department of Forestry (VDF) nursery located at the New Kent Forestry Center in Providence Forge, Virginia, and the Westvaco nursery located near Summerville, South Carolina.

### Experiment I

Thirty seedlings were sampled at both nurseries from all 5 seedlots approximately every 2 weeks from early November until mid-February. Occasionally lifting was postponed due to frozen ground in January or February. The roots were moistened and the samples immediately placed in plastic bags in a cooler with ice. The coolers were shipped to the Reynolds Homestead Research Center, in Critz, Virginia, to undergo RGP analysis.

Seedling RGP was determined using the system described elsewhere (DeWald 1986, Feret et al. 1985c). After 24 days the seedlings were removed from the trays, and root growth measured. The total length and total number of new long roots (>1.5 cm) and the total number of new short roots (>0.5 cm and <=1.5 cm) were determined for each seedling. Seedling RGP was thus expressed as the total length or total number of roots produced.

### Experiment II

On the final lift date of the season (mid-February), an additional 3,300 seedlings were lifted from each nursery. Seedlings were sorted and packaged into bundles of 33 seedlings for every treatment combination. The seedlings were packaged at each nursery, placed in kraft-polyethylene bags, and transported to the VDF Charlottesville cold storage facility where they were stored at 2°C.

The outplanting dates were every 3 weeks from early March until late May. On each date the seedlings were transported to the site where they were removed from the K-P bags. For each block, family, nursery, and planting date combination 8 of the 33 seedlings were randomly selected to undergo RGP analysis. The remaining 25 seedlings were planted. The 8 seedlings were transported for RGP analysis to the Reynolds Center (Critz, VA) immediately after planting was completed. The outplanting site was on a Westvaco Corporation tract located in Buckingham county on the Virginia Piedmont. The site had been operationally harvested, and site prepared by drum-chopping and burning.

### Experimental Design and Analysis

Both Experiment I and II were 3 treatment factorial experiments. In the outplanting of Experiment II, there were 4 field blocks. Analysis of all data was performed using the SAS statistical package (SAS Institute, Cary, N. C.). Using the measures of total length and total number of new roots, Analysis of Variance (ANOVA) was performed on the results to determine which effects and interactions were a significant component of seedling RGP variability. An alpha level of 0.01 was used for tests of significance.

Correlations were calculated to determine the degree of relation between RGP values at the time of planting, and subsequent survival and growth in the field. All data were also submitted to Duncan's New Multiple Range Test to determine where significant differences occurred.

## RESULTS AND DISCUSSION

### Experiment I

Root growth potential was measured as the mean total length and mean total number of new roots produced. Due to the very strong correlation ($r=.93$, $p<.001$) between number and length, only number of roots will be discussed. The RGP trend observed over the lifting season was that of low values during the early lifts of late October and November, followed by a sudden peak on the 5th lift in late December. RGP values then fell sharply, but rebounded with a second slightly lower peak on the last lift in mid-February (Figure 1). Seedlings from the Summerville nursery exhibited higher RGP than seedlings from the New Kent nursery on every lift date.

ANOVA results indicated that all main effects (lift date, nursery, and family), and all first

order interactions were highly significant (Table 1). The nursery x lift date interaction can be seen in Figure 1. Differences between nurseries were less pronounced when RGP levels were high. The strong family x nursery and family x lift date interactions were due to highly variable family rankings by lift date. Family means over the entire season ranked family 6-9 fifth when raised at New Kent, while 6-9 ranked second when it was grown at Summerville. RGP values for each family peaked on the same lift (5th), with the exception of 6-20, which had a second equally high value on the 8th lift.

Table 1. ANOVA table for number of new roots during the lifting season. F values are significant at $p < 0.001$.

| Source | df | SS | F |
|---|---|---|---|
| lift date | 7 | 16402.5 | 112.02 |
| nursery | 1 | 88822.7 | 424.47 |
| family | 4 | 17977.5 | 21.48 |
| nursery*family | 4 | 13552.6 | 16.19 |
| nursery*lift | 7 | 16673.4 | 11.38 |
| family*lift | 28 | 15134.1 | 2.58 |
| error | 2330 | 803821.8 | |

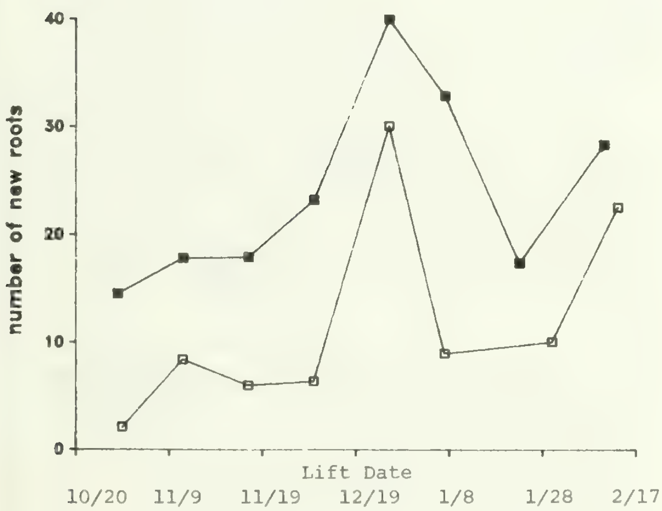


Figure 1. Mean number of new roots by nursery for the 1984-1985 lifting season. Open box plot=New Kent, Closed box plot= Summerville.

The observed pattern of low RGP values during the early lifts, and increasing values into the winter agree well with previous reports (Feret et al. 1985a, Brissette and Roberts 1984, Rhea 1977), with the exception of the late December peak, which occurred at both nurseries. No lifts were done after mid-February, hence the RGP decline associated with the rapid resumption of shoot growth reported in other studies was never observed in this study.

The large, consistent differences between nurseries could be due to many factors. Summerville seedlings had heavier lateral root systems and smaller shoots, perhaps due to the undercutting and lateral root pruning practiced at this nursery. In loblolly pine almost all of the new root growth observed in the RGP test originates on the lateral roots (DeWald 1986).

No prolonged window of high RGP levels was found, as has been reported for other species (Jenkinson 1984, Ritchie et al. 1985). RGP tended to increase and decrease sharply, with family rank changing markedly by lift date. This may have been simply sampling error, due to the small (30 seedling) samples for each family x nursery x lift date combination. If a minimum of 10 new roots is used as a threshold value, all seedlots except 11-137 were ready to be lifted after late October at Summerville. However, at New Kent, no two consecutive lifts averaged over 10 new roots.

Experiment II

RGP declined sharply in storage from fresh lift levels (Figure 2). However, RGP increased greatly on the fourth planting date, after approximately 12 weeks in cold storage. This resulted in the highest RGP values for New Kent seedlings, and the second highest values for Summerville seedlings over the entire storage duration. As no problems were noted at the Charlottesville storage facility, these RGP changes in cold storage were not related to equipment malfunction. The rapid decline of RGP in storage was unexpected and unusual. Other reports have shown loblolly pine can maintain its RGP for at least 12 weeks in cold storage (Barden and Feret 1986, Feret et al. 1985a).

Possible explanations for the decline in RGP are that the seedlings were stored too wet; this has recently been shown to reduce the RGP of seedlings cold stored in K-P bags (Barden and Feret 1986). Many examples of poor storage success with early lifted seedlings have been reported (Ritchie 1984, Ritchie and Dunlap 1980, Ritchie and Stevens 1979, Stone et al. 1979 However, in this study, the seedlings had received over 550 chilling hours at both nurseries. So chilling requirements were not likely a problem.

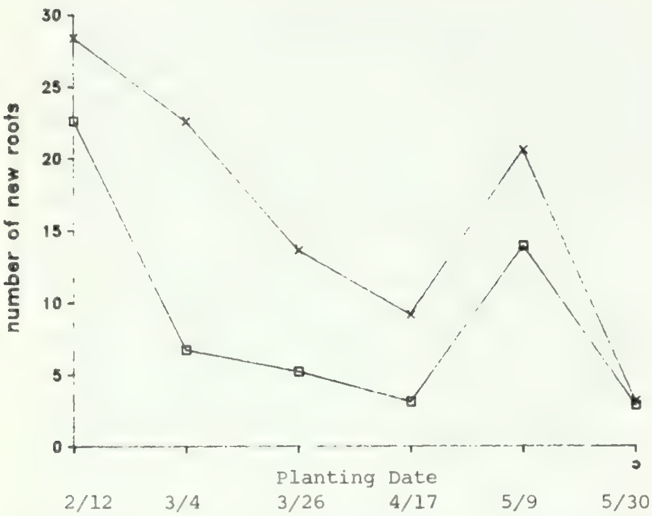


Figure 2. Mean number of new roots by nursery for the 1985 planting season. The first date indicates fresh lift levels. Open box plot=New Kent; "x" plot=Summerville.

Table 2. ANOVA table for number of new roots during the 1985 planting season. F values are significant at $p < 0.005$

| Source | df | SS | F |
|---|---|---|---|
| planting date | 4 | 44142.4 | 85.01 |
| nursery | 1 | 22195.7 | 170.97 |
| family | 4 | 6007.9 | 11.57 |
| block | 3 | 2557.9 | 6.57 |
| nursery*family | 4 | 2748.2 | 5.29 |
| nursery*planting date | 4 | 10008.7 | 19.27 |
| family*planting date | 16 | 4576.7 | 2.20 |
| error | 1562 | 200705.4 | |

The 5 seedlot RGP means of both nurseries followed virtually identical trends in storage (Figure 2). Early, rapid declines in RGP were followed by a sharp increase 12 weeks after lifting. Large increases have been observed in other studies, (Barden and Feret 1986, Feret et al. 1985c), just before and after rapid declines took place. An explanation for this "burst" of RGP may be that it is a response of the seedling to a stressful environment. The high RGP levels of the fourth planting date coincided with the highest survival of the study.

Summerville seedlings had consistently higher RGP than New Kent seedlings after storage (Figure 2). New Kent seedlings averaged less than 7 new roots on every planting date, except planting 4, while Summerville seedlings averaged more than 7 new roots for each storage duration, except planting 5.

ANOVA results indicated that all main effects (nursery, planting date, and family) were highly significant for RGP, and that all first order interactions were also highly significant (Table 2). The strong interactions were primarily due to family rank changes from nursery to nursery over the storage durations, and to the decreasing differences among nurseries over the longer storage durations.

There was no obvious trend in survival across planting dates, possibly due to increasing rainfall over the planting season. Summerville seedlings had significantly higher survival on all planting dates. Considering seedlots, only the seed orchard mix (42-M) had significantly higher survival overall. Some nursery x family interaction was evident, due to 6-8 having the lowest survival from New Kent, and the second highest from Summerville.

First year height increment was calculated for the surviving trees of each plot. There was a steady decline in height increment over the planting dates. There were large differences among families, and overall differences among nurseries were the most consistent effect. New Kent seedlings averaged only 55 % of the height increment that Summerville seedlings averaged. The differences among blocks ranged from 13.25 cm to 14.83 cm, and were the smallest of the main effects.

Field survival overall was significantly correlated with RGP ($r = .56$, $p<.01$). Simple linear regression was used to relate survival to new root number. Various transformations of number of new roots and survival were modeled. New root number regressed on the logit [$\log_{10}(y/1-y)$] of survival percentage provided the best fitting linear model (Figure 3a).

After sorting the data by planting date to eliminate the confounding effects of different soil and weather conditions, the fit of the various models improved greatly. The $\log_{10}$ transformation of new root number resulted in a good fit (Figure 3b-f). Only the final planting date (Figure 3f) failed to have a significant relationship between RGP and survival.

Height increment was significantly correlated with RGP over the first 4 planting dates. The overall correlation was moderately strong and highly significant ($r = .65$, $p<.01$). The trend of increasing height increment over increasing number of new roots was more nearly linear than the survival trend over RGP. Thus, various transformations only improved the model moderately. The final model used the square root of new root number (Figure 4a).

After sorting the data by planting date to eliminate the confounding effects of planting earlier or later in the season, the fit of the models increased greatly (Figure 4b-4f).

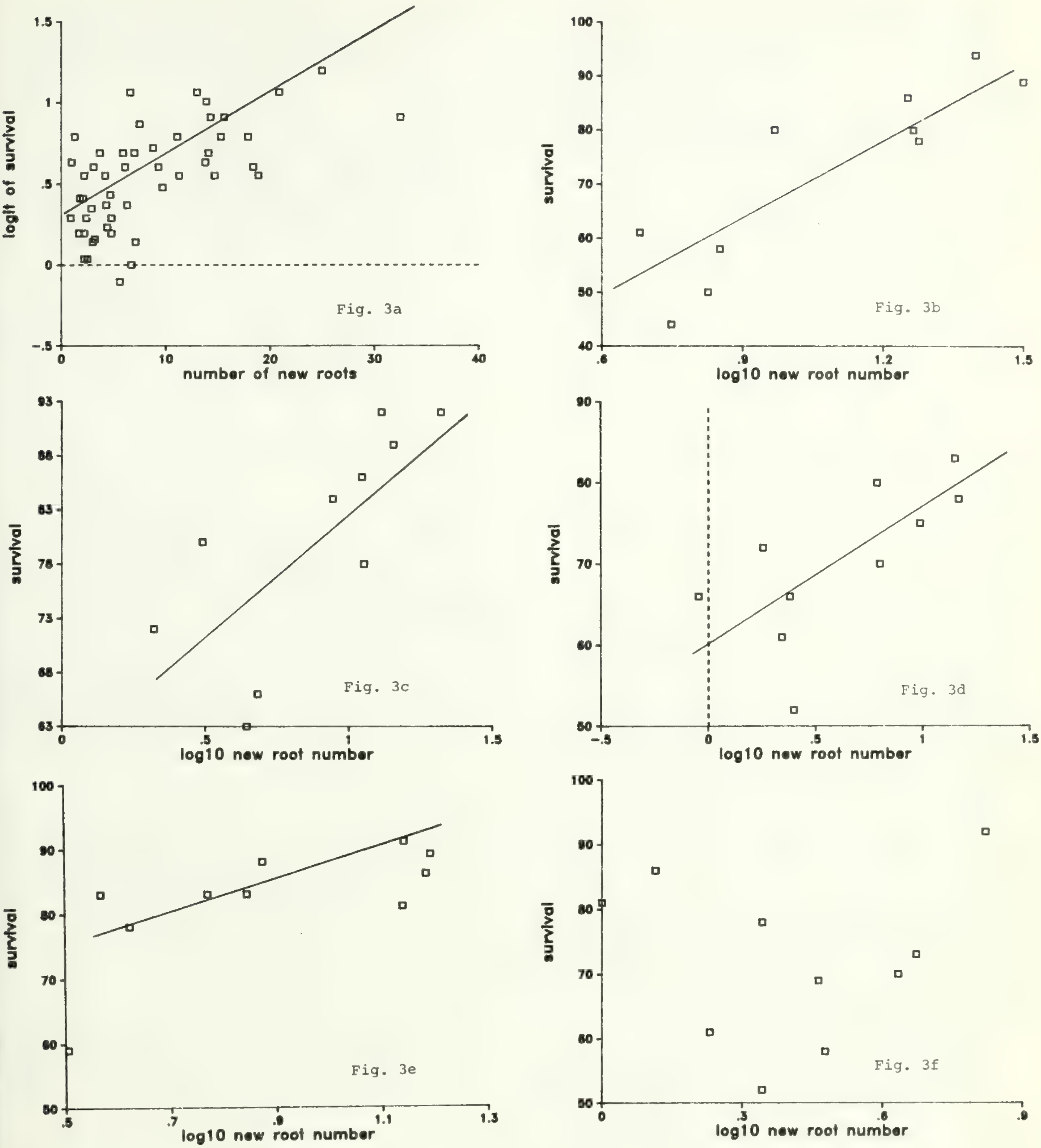


Figure 3. Relationship between field survival one year after planting and root growth potential measured as number of new roots. 3a. Overall relationship for 5 plantings ($r^2$=0.31; $p < 0.01$); 3b-3f, survival-RGP relationships for plantings 1-5 respectively ($r^2$=0.76, $p < 0.01$ for 3b; $r^2$=0.51, $p < 0.01$ for 3c; $r^2$=0.41, $p < 0.03$ for 3d; $r^2$=0.65, $p < 0.01$ for 3e; 3f no significant relationship.

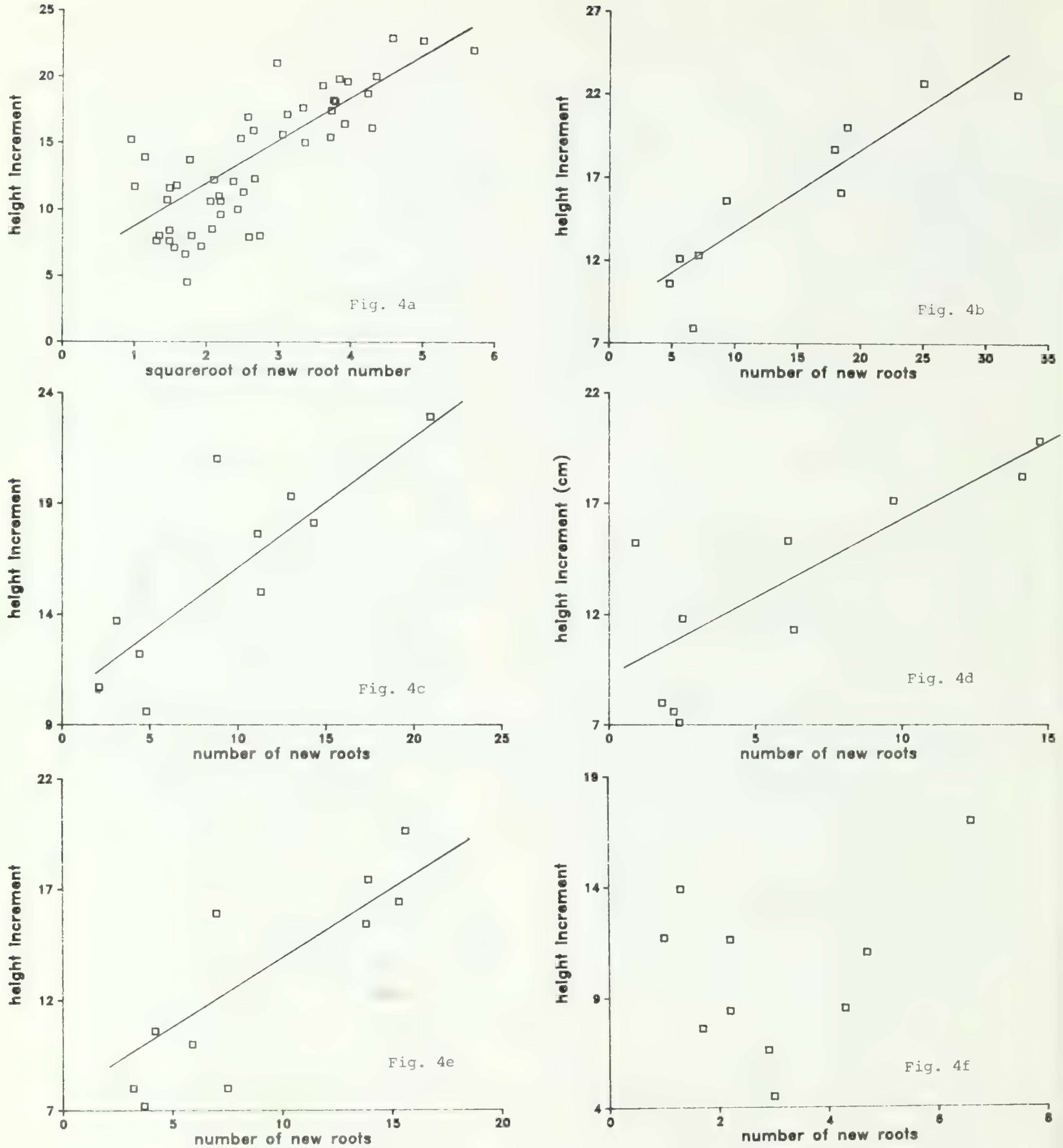


Figure 4. Relationships between first-year height increment and RGP. 4a. Overall relationship for 5 plantings ($r^2$=0.65, $p < 0.01$). 4b-4f, height increment-RGP relationships for plantings 1-5 respectively ($r^2$=0.80, $p < 0.01$ for 4b; $r^2$=0.68, $p < 0.01$ for 4c; $r^2$=0.60, $p < 0.01$ for 4d; $r^2$=0.61 $p < 0.01$ for 4e; 4f, no significant relationship.

Untransformed new root number provided the best fit, but the last planting date resulted in no significant relationship between height increment and RGP.

## SUMMARY

This study showed RGP to vary greatly by nursery, family, and lift date. Number and length of new roots were very highly correlated. The Summerville nursery consistently produced seedlings with higher RGP, although RGP patterns were very similar at both nurseries.

RGP was shown to be a good predictor of survival, and a better predictor of height growth, especially under stressful conditions. The lack of correlation on the last planting date was probably due to the narrow range of RGP values, (only 1-6 new roots (Figure 3f)), and the lack of stress after planting due to wet field conditions. RGP would logically be less critical for survival under well watered conditions, which would allow the planted, suberized roots to be adequate for moisture and nutrient uptake.

An asymptotic trend in survival was clearly evident. RGP in excess of 12 new roots yielded little improvement in survival (Figure 3a). A value of 10 or more new roots seemed to be neccesary to ensure survival of at least 80%.

Height growth was more strongly correlated with RGP than survival. The linear trend persisted up to RGP levels of 20 new roots. RGP increases approaching this value resulted in relatively smaller increases in height increment (Figure 4a).

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# ROOT GROWTH POTENTIAL AS A PREDICTOR OF FIRST YEAR FIELD PERFORMANCE FOR NON-IRRIGATED AND IRRIGATED EASTERN WHITE PINE SEEDLINGS[1/]

by

K. H. Johnsen, P. P. Feret, and J. R. Seiler[2/]

Abstract

Root Growth Potential (RGP) has been shown to be a good predictor of survival probability after outplanting. It has been suggested that the relationship between RGP and field performance might be strengthened when seedlings are planted on a stressful site. An experiment was conducted where seedlings of known RGP were planted at two levels of water stress. Eastern white pine (Pinus strobus L.) seedlings were hand lifted from nursery beds on eight occasions from October 15, 1985 to March 19, 1986. Seedlings from the first seven lifts were stored at 2 C and following the last lift date seedlings from all eight lift dates were included in a 21 day hydroponic RGP test. Due to the relationship of lift date and storage duration on RGP, this resulted in sets of seedlings with varying RGP. Subsets of seedlings from each lifting date were included in a field outplanting test. A split-plot design was used for the study with irrigated vs non-irrigated treatments as mainplots and lift date as subplots. RGP does show promise as a measure of eastern white pine seedling quality. The consistent ability of a seedling lot to produce new roots appears to be more important than the average number of new roots or morphological attributes in predicting field performance. RGP was significantly correlated with height increase and the relationship was strengthened on non-irrigated plots.

## INTRODUCTION

Good quality forest tree seedlings providing low mortality and rapid growth are always a desired component of any reforestation program. Nurserymen have long sought a seedling grading system that will accurately and consistently predict outplanting success. Although it has been decades since Wakeley (1949 ) first discussed the importance of seedling physiological status, morphological grading still remains the industry's principal method of rating seedling quality.

In 1955, Stone introduced the concept of Root Growth Potential (RGP) as a simple method of measuring the ability of a bare-root seedling to produce new roots after planting. Theoretically, a seedling with high RGP could rapidly re-establish contact with the soil and thus capitalize on available soil moisture and nutrients. More recently, Ritchie (1985) has suggested that RGP may be considered a general measure of seedling vigor because it is actually an indirect test of the status of several critical physiological systems.

Since being introduced by Stone, RGP has been the focus of numerous studies and, in general, RGP is a good predictor of seedling field performance. Direct relationships have been found between RGP and subsequent field performance in several members of the Pinaceae, including: loblolly pine (Pinus taeda L.), ponderosa pine (Pinus ponderosa Laws), lodgepole pine (Pinus contorta Dougl.), and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franko.) (Feret and Kreh 1985, Feret et al. 1985, Jenkinson 1978, Ritchie and Roden 1985, Ritchie and Dunlap 1980).

There have been several notable exceptions where RGP has not predicted or has been a poor predictor of first year survival and/or first year growth (Rhea 1977, Sutton 1980, Brissette and Roberts 1984, Dewald et al. 1985). In the latter two cases, the authors noted that first year survival was excellent and that field conditions were not very stressful. This implies that differences in root growth and general physiological condition may be of varying importance under different field conditions.

This study was undertaken to examine the relationship of RGP and first year field performance under two levels of moisture stress using eastern white pine (Pinus strobus L.). There have been no previously reported experiments examining RGP/field performance with eastern white pine. An understanding of RGP/field performance relationships might be helpful for allocating seedlings of differing physiological quality to sites of varying quality.

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METHODS AND MATERIALS

2-0 eastern white pine seedlings were hand lifted on eight occasions from October 18, 1985 to March 19, 1986. Seedlings were lifted from the Virginia Division of Forestry's Augusta nursery (Waynesboro, VA.). On each lift date, seedlings were randomly selected from each of three pre-established blocks. Seedlings from the first 7 lift dates were double wrapped in polyethylene bags and placed into cold storage at 2 C.

Following the last lift date, 15 seedlings per block/lift date combination were included in a 21 day hydroponic RGP test as described by Dewald et al.(1984). Blocking for the RGP test was maintained as from the nursery. Following the test new white roots greater than or equal to 0.5 centimeter in length were counted. Dry weight of roots and shoots were determined after drying to a constant weight at 60 C.

Three days after the initiation of the RGP test (March 23 and 24, 1976) subsamples from each block/lift date combination were outplanted at the Reynolds Homestead Research Center (Critz, Virginia). The outplanting consisted of three replicate blocks (maintained as from the nursery and the RGP test) planted on a plowed and disked old field site. A split-plot design was used with irrigated vs non-irrigated treatments as the mainplot and lift dates as subplots. Each mainplot was then randomly planted, using 0.5 meter spacing, with eight seedlings from each of the appropriate block/lift date combinations. Seedlings were root pruned to 12 cm below root collar, the same procedure used for the RGP test.

Drip irrigation was provided around the stem of each seedling in a irrigation treated mainplot. Water was provided as needed so that irrigated trees received no less than 2.54 centimeters of natural and/or supplemented precipitation per week. On July 17, all plots were hand weeded. On two dates, June 24 and July 17, mid-day needle water potential was measured on two randomly selected seedlings from each outplanting mainplot for both the January 3 and the March 19 lift dates. Seedling water potential was measured on a single needle fascicle using a pressure bomb.

Seedling height growth and diameter growth was determined by measuring seedlings at time of outplanting and again on September 5. Survival data was collected on May 30, June 24, July 17, and September 5.

To assess the effect of the irrigation treatment, seedling water potential, survival, height growth, and diameter growth were analyzed using Analyses of Variance with a split-plot design. General linear regression was used to determine the relationships between morphological traits and RGP measurements to survival, height growth, and diameter growth. Morphological traits used were root collar diameter, shoot weight, root weight, and root/shoot ratio. RGP measurements used were number of roots and percent poor seedlings (a poor seedling was defined as one producing less than 2 new roots). Analyses were made using block means. Data from irrigated and non-irrigated treatments were analyzed separately.

RESULTS

IRRIGATION TREATMENTS

Analyses of variance showed no significant effect due to irrigation on end of season survival, height increment, relative height increment (height increment/initial height), diameter increment, and relative diameter increment (diameter increment/initial diameter). Survival as measured on May 30 and seedling water potential as measured on both June 24 and July 17 did show significant differences in irrigation treatment at the alpha = 0.05 level. Means for both irrigation treatments are shown in Table 1.

Table 1. Means of first year field performance for irrigated (IRR) and non-irrigated (NON) eastern white pine seedlings.

| | IRR | NON IRR | |
|---|---|---|---|
| % Survival (May 30) | 89 | 77 | ** |
| % Survival (Sept. 5) | 74 | 76 | ns |
| Hgt Increment (cm) | 10.10 | 8.00 | ns |
| Relative Hgt. Inc. (Hgt Inc./initial hgt.) (%) | 48 | 40 | ns |
| Diameter Increment (mm) | 1.76 | 1.69 | ns |
| Relative Diam. Inc. (Diam. inc./init. diam.) (%) | 44 | 44 | ns |
| Needle Water Potential (MPa) | | | |
| June 24 | -1.13 | -1.58 | ** |
| July 17 | -1.18 | -1.57 | ** |

ns P > 0.10 : * P < or = 0.10 ; ** P < or = 0.05;

*** P < or = 0.01

Precipitation data for the time period studied and survival for two irrigation treatments are shown in Figures 1 and 2, respectively.

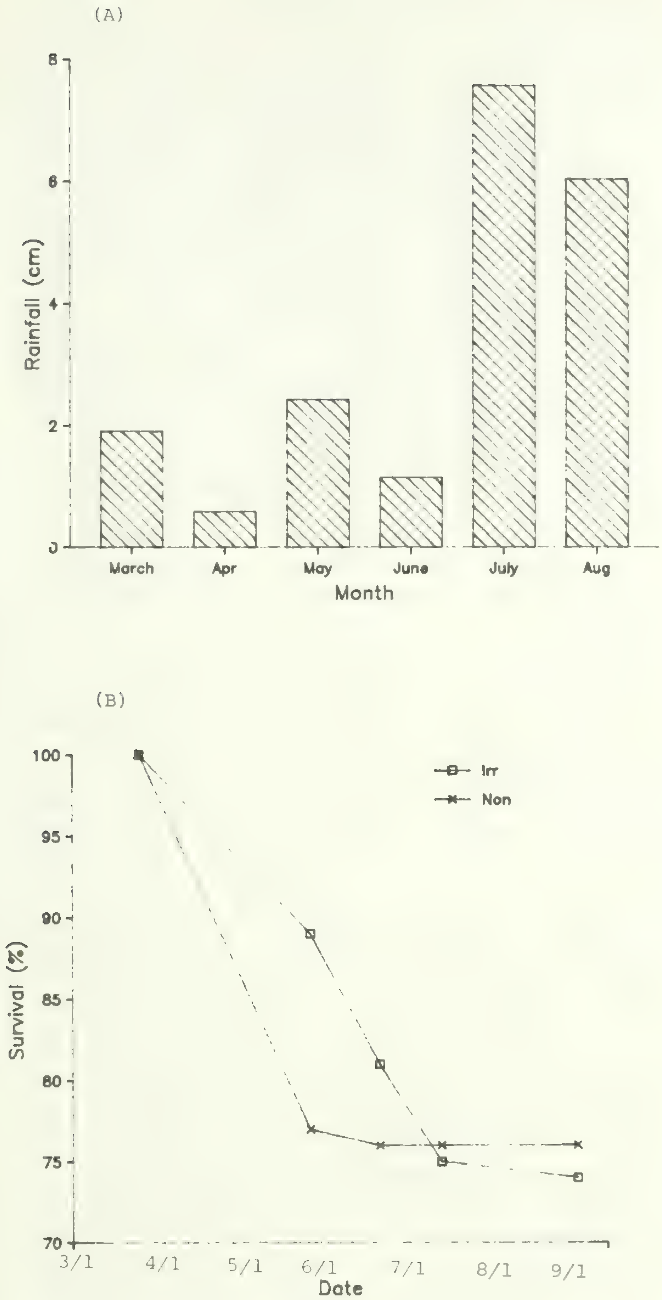


Figure 1. (A) Spring and summer precipitation at Reynolds Homestead Research Center, Critz, VA. and (B) first year survival for irrigated (Irr) and non-irrigated (Non) outplanted eastern white pine seedlings.

PREDICTIONS OF FIELD PERFORMANCE

Morphological traits.- With a few exceptions, morphological traits were generally not significantly correlated to field performance (Table 2). Root/shoot ratio was significantly and positively correlated (P $\leq$ .05) .05) to height increment on non-irrigated plots. Root collar diameter was significantly and positively correlated in one instance but was not a consistent predictor of first year field performance.

Seedling RGP.- Seedling RGP was more consistently correlated with first year field performance than morphological traits (Table 2). Although RGP was inconsistent in predicting seedling survival and showed no significant correlations with diameter increment, it was a consistent predictor of relative height increment. RGP showed better correlations with height increment on non-irrigated plots. RGP as measured as percent poor trees (percentage of seedlings in RGP test growing less than 2 new roots) was more often correlated with field performance than RGP as measured by average number of new roots.

F tests show no significant differences in slope or intercept between irrigated and non-irrigated data in a regression of % poor trees on relative height increment. However, when separate equations are fit to both sets of data, the regression using the non-irrigated data provides a much better fit than that using the irrigated data (Figure 2).

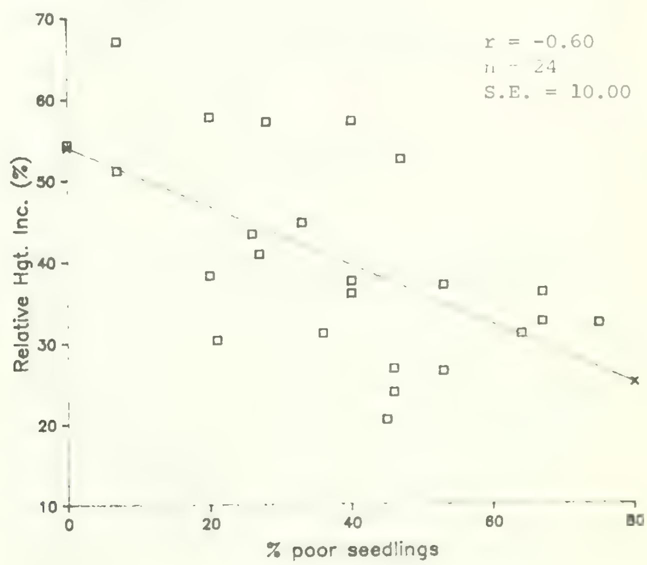


Figure 2.--Relationship between percent poor seedlings and relative height increment for non-irrigated outplanted 2-0 eastern white pine seedlings

Discussion

Although there were no significant irrigation differences as reflected in end of season survival or growth, there were definite differences in seedling stress levels between the two treatments as is seen by the significant differences in seedling water potential. Irrigation seems to have postponed mortality (Figure 1) but did not prevent it. Apparently, certain seedlings were of such low quality that

Table 2.—Correlations (n = 24) between first year field performance and Root Growth Potential (RGP) and morphological traits of irrigated (Irr.) and non-irrigated (Non.) eastern white pine seedlings.

| Field Performance | | Seedling RGP: New roots (number) | Seedling RGP: % poor seedlings (%) | Morphological traits: Root collar diameter (mm) | Morphological traits: Shoot wgt. (g) | Morphological traits: Root wgt. (g) | Morphological traits: Root to shoot ratio |
|---|---|---|---|---|---|---|---|
| Survival (%) | | | | | | | |
| May 30 | Irr. | .05 ns | -.25 ns | .00 ns | .33 ns | .31 ns | .01 ns |
| | Non. | .04 ns | -.15 ns | .03 ns | .06 ns | .10 ns | .10 ns |
| Sept. 5 | Irr. | .09 ns | -.44** | .00 ns | .33 ns | .31 ns | .29 ns |
| | Non. | .10 ns | -.22 ns | -.07 ns | .04 ns | .03 ns | .16 ns |
| Height increment | | | | | | | |
| Total (cm) | Irr. | .20 ns | -.31 ns | .36* | .05 ns | .11 ns | .31 ns |
| | Non. | .25 ns | -.52*** | .31 ns | .03 ns | .27 ns | .44 ** |
| Relative (%) | Irr. | .24 ns | -.37* | .03 ns | .15 ns | .01 ns | .29 ns |
| | Non. | .40** | -.60*** | .06 ns | .01 ns | .26 ns | .47** |
| Diameter increment | | | | | | | |
| Total (cm) | Irr. | .25 ns | -.08 ns | .13 ns | .18 ns | .21 ns | .13 ns |
| | Non. | .09 ns | -.21 ns | .40** | .12 ns | .05 ns | .21 ns |
| Relative (%) | Irr. | .21 ns | -.16 ns | —[1] | .02 ns | .05 ns | .11 ns |
| | Non. | .04 ns | -.10 ns | —[1] | .17 ns | .23 ns | .16 ns |

ns P > or = 0.10 ; * P < or = 0.10 ; ** P < or = 0.05 ; *** P < or = 0.01

[1] regression not run due to dependency of variables

they could not survive even with sufficient moisture.

It is not surprising that first year height growth did not differ significantly between irrigation treatments as eastern white pine exhibits fixed growth which is highly influenced by production of needle primordia the previous summer in the nursery. Since relative height increment was increased 17% on irrigated plots, it does appear that cell elongation and/or division of the rib meristem was enhanced by irrigation. The lack of any difference in relative diameter increment may have been because most diameter growth occurs in the second half of the summer and by then rainfall was providing more adequate soil moisture.

RGP was a better predictor of height increment on non-irrigated plots than on irrigated plots. It appears that performance attributes such as RGP and some material attributes such as root/shoot ratio become more influential on first year field performance as field conditions become more severe.

Percent poor trees accounted for 36% of the variation in relative height growth of non-irrigated trees which was considerably better than any morphological trait. Since eastern white pine is a determinant species, RGP may provide as good or better correlations with second year growth. General vigor during the first summer could potentially impact needle

primordia production which will largely determine the next years growth.

Although RGP did not show a good linear relationship with survival, it does seem to have some value as a predictor of seedling survival. Figure 3 shows a plot of percent survival vs percent poor seedlings for both irrigated and non-irrigated trees. There appears to be a threshold level at about 35 percent poor seedlings below which there is consistently high outplanting survival. Seedling lots with less than 35 percent poor seedlings (42 percent of those tested) in the RGP test resulted in an average of 88 percent survival with a coefficient of variation (C.V.) of 15 percent. Seedling lots with over 35 percent poor seedlings in the RGP test were highly variable in survival response and resulted in an average of 66 percent survival with a C.V. of 38 percent. Irrigated and non-irrigated seedlings show approximately the same response.

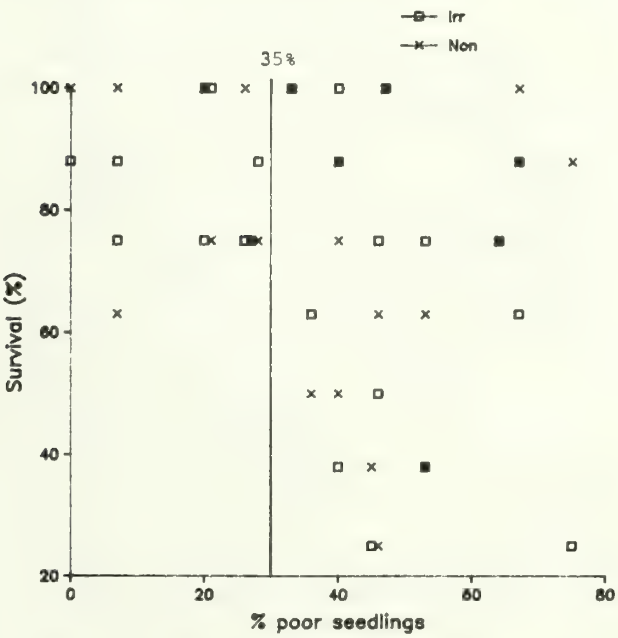


Figure 3.--Relationship between percent poor seedlings and first year survival for irrigated (Irr) and non-irrigated (Non) outplanted 2-0 eastern white pine.

Percent poor trees was a better predictor of both survival and height growth than average number of new roots. This indicates that, with eastern white pine, RGP may be more important as a general measure of seedling vigor than as a measure of a seedlings ability to renew intimate contact with the soil. Kramer (1985) indicated that in some species suberized roots may be more efficient at water and ion uptake than is generally thought. Therefore, the difference in subsequent field performance, from a RGP of 0 to 2 new roots may be greater than from 2 to 10 new roots. The difference is really the ability of the seedling to be or not to be physiologically active. This point may seem very obvious but as this measure of seedling quality is visually indistinguishable between seedling lots, the Root Growth Potential test is a valuable method of measuring general seedling physiological condition.

## Conclusions

It appears from this study that RGP does show promise as a measure of the quality of eastern white pine seedlings. The consistent ability of a of a seedling lot to produce roots appears to be more important than the average number of new roots or than it's morphological attributes in predicting field performance. A threshold seems exist where the best seedlings, by measuring percent poor seedlings, provide consistently excellent survival. RGP is significantly correlated with height increase and the relationship is strengthened on non-irrigated plots.

ACKNOWLEDGEMENT:-- We appreciate the cooperation of Wayne Mcbee and Tom Dierauf of the Virginia Division of Forestry without which this study could not have been accomplished.

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## Soil-Site-Stand Relationships

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INTEGRATED SITE CLASSIFICATION IN THE SOUTHERN APPALACHIANS:

GEOLOGIC VARIABLES RELATED TO YELLOW-POPLAR PRODUCTIVITY[1/]

W. Henry McNab[2/]

Abstract.--Stand characteristics of yellow-poplar were significantly different for sample plots located on colluvial soils derived from metamorphosed igenous rocks compared with soils derived mostly from metamorphosed coarse clastic sedimentary rocks in the Bald Mountains of North Carolina. Mean site index and d.b.h. did not differ between rock classes. Analysis of covariance, with mean stand age as covariate, indicated that stands over igneous rocks had an average of 30 more yellow-poplar trees per acre and 37 ft$^2$ more basal area than stands on sedimentary rocks. There was no difference in the density and basal area of other species. Available geologic mapping, even at a scale of 1:250,000, appears to provide useful information as a component in a hierarchical site classification system for other areas in the Southern Appalachians.

## INTRODUCTION

The geology of the Southern Appalachian Mountains is a complex arrangement of rock types that can vary widely in physical and chemical properties over relatively small areas. Geologic components could account for some of the variation in application of soil-site relationships beyond the original study area and help explain the sometimes marked differences in species composition and productivity of hardwood stands in adjacent watersheds. It is well known that the chemical and physical characteristics of soils largely result from lithologic properties of the parent material. Although modern soil mapping is well under way in many mountainous counties, the pace is slow and few reports have been published that could be useful in site classification and evaluation. Also, the value of soil series in the accurate evaluation of site productivity is sometimes questioned. If stand productivity is related to parent rocks, however, then geology could provide immediate useful information at an upper level of a multicomponent site classification to gain accuracy in prediction of site and stand characteristics.

Information is relatively abundant relating overstory and understory species associations with soils derived from various parent materials. However, little has been reported on correlations of the tree overstory productivity with geologic factors, especially in the Southern Appalachians. Graves and Monk (1985) reported that tree species and basal area were not significantly different between two adjacent sample locations in northeast Georgia: one over marble and limestone parent rocks, and the other over schist. Rohrer (1983) studied vegetation over three rock groups in northwestern North Carolina and reported that each group weathered into soils with different texture, mineralogical composition, and moisture availability regimes. He found that density and basal area of tree species, expressed in relative terms as importance values, were closely correlated with rock group.

Geologically, all rocks are placed into three classes: igneous, sedimentary, and metamorphic, depending on their origin (Whiteside 1953). Rock class is commonly used in soil classification and is usually readily obtainable from small-scale generalized geology maps. Warren and Matheson (1949) found rock class helpful in classifying sites in British Columbia for productivity of Sitka spruce (*Picea sitchensis* (Bong.) Carr.). The most productive sites were associated with sedimentary rock formations in comparison with nearby lower quality sites on igneous rocks. Information on the relative value of geologic variables is needed for a proposed multicomponent site classification being developed for the Southern Appalachians.[3/]

A study was designed to test the null hypothesis that parent rock has no effect on characteristics of yellow-poplar (*Liriodendron tulipfera* L.) stands. The study has the specific objectives of evaluating the effects of parent rock on site quality, growth and yield, and herbaceous vegetation. Results have been summarized on the value of geological variables in modeling site index as

[1/] Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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[3/] McNab, W. Henry. Rationale for a multifactor forest site classification system for the Southern Appalachians. In preparation.

a function of topography.[4] The purpose of this symposium paper is to present results of the effects of geologic rock units on stand characteristics.

## METHODS

The study site was located along a 30-mile segment of the Bald Mountains of western North Carolina in Madison and Haywood Counties, along the boundary with Tennessee. The town of Hot Springs roughly bisects the study area. Elevations in this area range from 1,500 to 2,000 feet in intermountain basins to more than 4,000 feet at several mountain summits. Soils on high-quality sites are mesic Typic Hapludults and Umbric Dystrochrepts that have formed in colluvium on lower slopes and in coves. Slope gradients range from 10 to >60 percent. Precipitation at Hot Springs averages 45 inches annually, but increases at higher elevations. The Bald Mountains were selected for this study because of their nearness to Asheville and the availability of National Forest lands for plot installation, but primarily because the contact zone of several major lithostratigraphic units occurs within these mountains.

Most of the rocks in.this area are predominantly quartzo-feldspathic, and thus are relatively low in mafic minerals such as hornblende, biotite, and Ca-rich plasioclase feldspar. The igneous rocks are mostly late to middle Proterozoic granitic to granodioritic gneisses. The sedimentary rocks are coarse to fine-grained clastics in the late Proterozoic Ocoee Supergroup, which includes the Walden Creek Group, undivided, the Snowbird Group, undivided, and the Longam Quartzite of the Snowbird Group. Both rock classes have undergone low- to middle-grade regional metamorphism. Except for intensive study of the Hot Springs "geological window" in Madison County, no detailed geological mapping is available.

A total of 60, circular 1/4-acre plots were located in even-aged yellow-poplar stands. Only stands with 75 percent or more of yellow-poplar in the overstory were sampled. Plots were grouped in clusters of 5 to 10 plots each to provide replication within a specific type of rock. Increment cores were taken from three to four dominant and codominant yellow-poplar trees in each plot to estimate mean stand age. Each tree sampled for age was also measured for total height. Site index was determined by height-age curves developed by Beck (1962). All trees >4.5 inches d.b.h. in the plots were recorded by species, diameter class, and canopy crown class. The lower crown class included suppressed and intermediate trees; codominants and dominants were placed in the upper class. Besides yellow-poplar, other common deciduous overstory species included sweet birch (Betula lenta L.), northern red oak (Quercus rubra L.), and black locust (Robinia pseudoacacia L.). Red maple (Acer rubrum L.), flowering dogwood (Cornus florida L.), and sourwood (Oxydendrum arboreum (L.) DC.) formed a large proportion of understory species. Two coniferous species, eastern hemlock (Tsuga canadensis (L.) Carr.) and eastern white pine (Pinus strobus L.), were occasionally found in the understory. Rhododendron maximum L. was the principal shrub species, particularly where sample plots were adjacent to streams. For the most part, the yellow-poplar overstory was even-aged, but some stands included an occasional large tree, presumably a residual from past harvesting activities. Field data were summarized by two groups--yellow-poplar and miscellaneous species.

Following plot establishment, rock type was determined by sampling half of the plots in each cluster. Rock types were combined in six groups according to origin, texture, mineralogical composition, and other data.[5] Geological characteristics of the rock groups have been summarized--each rock class consists of two or more rock groups; each group contained from three to six rock types; in addition, site index was summarized by rock class.[6] This work indicated that although site index did not differ by rock class, it was correlated with a different set of topographic variables associated with each rock class.

Rock class is used in this report because it can readily be determined from small-scale geological maps. Stand conditions by rock class are presented in table 1. The majority of sample stands were from 50 to 60 years of age and ranged from 110 to 130 in site index. Generally, sample stands on both rock classes were on similar landforms and had similar topographic characteristics except that few plots on sedimentary rocks were on south-facing aspects.

The effect of rock classes on tree density and basal area was determined by analysis of covariance, using mean stand age as the covariate. Chi-square analysis was used to compare tree counts in d.b.h. classes. All tests of significance were made at the 0.05 level of probability.

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[6] See footnote 4.

Table 1.--Distribution of sampled yellow-poplar stands, by site index class, rock class, and stand age

| Site index | Rock class | Stand age class (years) 30 | 40 | 50 | 60 | 70 | 80 | Total |
|---|---|---|---|---|---|---|---|---|
| | | -- Number of stands -- | | | | | | |
| 100 | Igneous | -- | -- | 1 | -- | -- | -- | 1 |
| | Sedimentary | -- | -- | -- | -- | 1 | -- | 1 |
| 110 | Igneous | -- | -- | 2 | 1 | -- | -- | 3 |
| | Sedimentary | 3 | 1 | 4 | 2 | 3 | -- | 13 |
| 120 | Igneous | -- | 4 | 5 | -- | -- | -- | 9 |
| | Sedimentary | -- | 3 | 4 | 6 | 1 | 1 | 15 |
| 130 | Igneous | -- | -- | 4 | 4 | -- | -- | 8 |
| | Sedimentary | -- | -- | 2 | 4 | 1 | 1 | 8 |
| 140 | Igneous | -- | -- | 1 | -- | -- | -- | 1 |
| | Sedimentary | -- | -- | 1 | -- | -- | -- | 1 |
| All | Igneous | -- | 4 | 13 | 5 | -- | -- | 22 |
| | Sedimentary | 3 | 4 | 11 | 12 | 6 | 2 | 38 |
| Total both | | 3 | 8 | 24 | 17 | 6 | 2 | 60 |

RESULTS AND DISCUSSION

Density of Tree Stand

Density of the average tree stand on the two rock classes is shown by species and overstory crown class in table 2. Correction for variable stand age by covariance analysis had little effect on the mean values. For the total stand, significantly more total trees and trees in the upper crown canopy class were present on igneous rocks compared with sedimentary rocks. About 20 more trees per acre in both crown classes were present in plots over igneous rocks.

Most of the total stand differences resulted from the yellow-poplar component. Yellow-poplar stands over igneous rocks have an average of 15 more trees per acre in the lower canopy class and 22 more in the upper crown class than the stands over sedimentary rocks. The number of yellow-poplars per acre on sedimentary rocks was about equally distributed between lower and upper crown classes. However, on igneous rocks, an average of almost 10 more trees per acre were in the upper crown canopy.

For the miscellaneous species, the ratio of trees in the lower and upper crown classes was about the same for both rock classes. About 11 percent of the overstory consisted of species other than yellow-poplar on igneous rocks, and about 16 percent on sedimentary rocks.

Table 2.--Density of average stand of yellow-poplar and miscellaneous species, by crown canopy class and rock class

| Rock class | Crown canopy class Lower | Upper | Both classes |
|---|---|---|---|
| | ------- Number per acre -------- | | |
| | YELLOW-POPLAR | | |
| Igneous | 53.0 | 62.0* | 115.0* |
| Sedimentary | 39.4 | 41.4 | 80.8 |
| | MISCELLANEOUS SPECIES | | |
| Igneous | 66.9 | 7.7 | 74.6 |
| Sedimentary | 71.6 | 8.2 | 79.8 |
| | TOTAL STAND | | |
| Igneous | 119.9 | 69.7* | 189.6* |
| Sedimentary | 111.0 | 49.6 | 160.6 |

*Significant at 0.05 level of probability.

Basal Area

Average basal area of the stands (table 3) follows almost the same pattern of statistical significance as the tree stand. In soils derived from igneous rocks, the total stand has almost 50 percent more basal area in the upper crown class and in both crown classes than stands over sedimentary rocks. As with stand density, most of this difference is attributable to the yellow-poplar stand component. Basal area of yellow-poplar in the upper canopy was over twice that of the lower crown component. This ratio was reversed for miscellaneous species, where the understory contained twice the basal area of the overstory. From 12 to 13 percent of overstory basal area consisted of miscellaneous species for stands on both classes of rocks.

Diameter at Breast Height

Quadratic mean tree d.b.h. is shown is table 4. Although no statistical tests were made, it seems apparent there are no real differences in mean d.b.h. of stands on igneous and sedimentary rocks, when averaged over all densities and ages. Yellow-poplars in the overstory averaged almost 16 inches and were more than 5 inches greater in d.b.h. than those in the understory. In comparison, miscellaneous species in the overstory averaged 8 inches greater than the understory component. Much of this diameter advantage resulted from scattered residuals in the 21- to 29-inch d.b.h. classes. Averaged over both crown classes

in the stand, the miscellaneous species component was about 3 inches smaller in d.b.h. than the yellow-poplar component.

Table 3.--Mean basal area of yellow-poplar and miscellaneous species, by crown canopy class and rock class

| Rock class | Crown canopy class Lower | Upper | Both classes |
|---|---|---|---|
| | $ft^2$/acre | | |
| | YELLOW-POPLAR | | |
| Igneous | 29.0 | 85.5* | 114.5* |
| Sedimentary | 21.8 | 55.5 | 77.3 |
| | MISCELLANEOUS SPECIES | | |
| Igneous | 28.0 | 12.9 | 40.9 |
| Sedimentary | 28.1 | 12.8 | 40.9 |
| | TOTAL STAND | | |
| Igneous | 57.0 | 98.4* | 155.4* |
| Sedimentary | 49.9 | 68.3 | 118.2 |

*Significant at 0.05 level of probability.

Table 4.--Average d.b.h. of yellow-poplar and miscellaneous species, by crown canopy class and rock class

| Rock class | Crown canopy class Lower | Upper | Both classes |
|---|---|---|---|
| | Inches | | |
| | YELLOW-POPLAR | | |
| Igneous | 10.0 | 15.9 | 13.5 |
| Sedimentary | 10.1 | 15.7 | 13.2 |
| | MISCELLANEOUS SPECIES | | |
| Igneous | 8.8 | 17.5 | 10.0 |
| Sedimentary | 8.5 | 16.9 | 9.7 |
| | TOTAL STAND | | |
| Igneous | 9.3 | 16.1 | 12.2 |
| Sedimentary | 9.1 | 15.9 | 11.6 |

## Stand Diameter Distribution

The average distribution of trees by d.b.h. class is shown in table 5. Because relatively few trees were over 20 inches in diameter, trees larger than 20.5 inches d.b.h. were grouped into a single class. Only 2 percent of all trees measured were in the 21+ inches d.b.h. class. Most of these trees, 47 out of 61, were in the 21 to 23 inches d.b.h. range. About two to four more yellow-poplars in each d.b.h. class from 7 to 18 inches were present on igneous rocks than on sedimentary rocks. Although the numbers of trees per acre differed significantly by rock class (table 2), chi-square analysis indicated no significant difference in the proportion of trees in diameter classes by rock class for either yellow-poplar, miscellaneous species, or the total stand.

Diameter distribution of the tree populations was similar on both rock classes. Yellow-poplar and miscellaneous species were unimodal at the 14 and 6 inches d.b.h. classes, respectively. The median diameter was 12.5 inches for yellow-poplar and 7.5 inches for miscellaneous species.

## Comparison with Standard Distribution

In table 6, d.b.h. distributions from this study are compared with similar data presented by McGee and Della-Bianca (1967), which apply to predominantly yellow-poplar stands in the Southern Appalachian Mountains from north Georgia to Virginia. Two test stands on each rock class were synthesized from the sample plot data for comparison with published data. The mean d.b.h. distribution of each test stand was determined from data for four plots with the same site index class, age class, and tree density class. Because the mean tree density of the four samples in each group did not exactly match a published stocking value, the number of trees in each diameter class was expressed as a percentage of the total number of trees per acre. Thus, each of the four test stands has a bimodal diameter distribution, indicating the presence of an understory with a mean diameter of from 6 to 8 inches.

Results of the chi-square analysis indicated no real differences between the yellow-poplar stands on igneous rocks in the study and the published results. Both test stands had slightly more trees in the smaller diameter classes. For example, the median d.b.h. was about 10 inches for the synthesized stand with 120 site index and 50 years of age. In comparison, half of the trees were 11 inches or smaller in the published distribution. Mean stand basal area was only about 4 percent less than the published values.

The diameter distribution differed significantly from published results for the two synthesized stands on sedimentary rocks. In both test stands, more trees of smaller diameter and fewer large trees were present compared with published data. For the stands with 120 site index and age 50, the median d.b.h. classes were separated by almost two diameter classes. The test and pub-

lished diameter distributions differed even more for the site index 130 comparison, where the median stand d.b.h. classes were separated by five size classes. Mean basal area was 17 to 41 percent less than expected.

## SUMMARY AND CONCLUSIONS

Characteristics of yellow-poplar stands measured at various locations within the Bald Mountains of North Carolina were significantly related to the geologic rock class. Yellow-poplar stands on soils derived from igneous rocks had significantly greater tree density and basal area than similar stands over sedimentary rocks. In comparison with published data, the diameter distribution of yellow-poplar stands on igneous rocks was close to the expected ratios. But on sedimentary rocks, the sample stands did not fit the predicted diameter distributions. Characteristics of stands on sedimentary rocks were similar to those of stands 10 to 20 units lower in site index on igneous rocks in this study and in comparison with published results. In addition to productivity, geologic variables may also provide information on forest management problems associated with stand regeneration and species composition.

Although stands on sedimentary rocks were less productive than those on igneous rocks in this study, these results do not apply to igneous and sedimentary rock units elsewhere because other lithologic characteristics such as mineral content, texture, and grain size may be quite different.

Further research on how geologic variables influence stand productivity on other sites and for different species is recommended. Correlations among geologic variables and soil characteristics affecting stand characteristics should also be studied.

Table 5.--Distribution of trees on plots dominated by yellow-poplar overstory, by diameter class and rock class

| Rock | D.b.h. class (inches) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| class | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21+ | Total |
| | Number per acre | | | | | | | | | | | | | | | | | |
| | YELLOW-POPLAR | | | | | | | | | | | | | | | | | |
| Igneous | 3 | 4 | 6 | 9 | 8 | 8 | 9 | 10 | 11 | 12 | 9 | 9 | 7 | 4 | 3 | 3 | 3 | 118 |
| Sedimentary | 1 | 3 | 4 | 5 | 5 | 6 | 7 | 5 | 7 | 8 | 7 | 5 | 4 | 3 | 2 | 2 | 3 | 77 |
| | MISCELLANEOUS SPECIES | | | | | | | | | | | | | | | | | |
| Igneous | 11 | 12 | 12 | 10 | 7 | 6 | 3 | 4 | 3 | 3 | 2 | 1 | 1 | 1 | 0 | 0 | 1 | 77 |
| Sedimentary | 9 | 15 | 12 | 9 | 6 | 6 | 4 | 4 | 4 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 78 |
| | ALL SPECIES | | | | | | | | | | | | | | | | | |
| Igneous | 14 | 16 | 18 | 19 | 15 | 14 | 12 | 14 | 14 | 15 | 11 | 10 | 8 | 5 | 3 | 3 | 4 | 195 |
| Sedimentary | 10 | 18 | 16 | 14 | 11 | 12 | 11 | 9 | 11 | 10 | 8 | 6 | 5 | 4 | 3 | 3 | 4 | 155 |

Table 6.--Mean diameter distribution of natural yellow-poplar stands growing on two classes of rocks in Madison and Haywood Counties, NC, compared with diameter distributions reported by McGee and Della-Bianca (1967)

| Data source | Basal area | Trees per diameter class (inches) | | | | | | | | | | | | | | | | | Total trees |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21+ | |
| | $ft^2$ | Percent | | | | | | | | | | | | | | | | | No. |
| IGNEOUS ROCKS, SITE INDEX 120, AGE 50 | | | | | | | | | | | | | | | | | | | |
| Test | 165 | 9 | 7 | 11 | 9 | 8 | 6 | 8 | 6 | 9 | 6 | 4 | 4 | 6 | 3 | 2 | 1 | 1 | 211 |
| Published | 172 | 2 | 5 | 7 | 8 | 8 | 9 | 9 | 8 | 8 | 7 | 7 | 6 | 5 | 5 | 3 | 3 | 0 | 200 |
| IGNEOUS ROCKS, SITE INDEX 130, AGE 50 | | | | | | | | | | | | | | | | | | | |
| Test | 165 | 5 | 3 | 5 | 10 | 5 | 3 | 4 | 11 | 6 | 9 | 9 | 9 | 5 | 5 | 3 | 3 | 5 | 164 |
| Published | 171 | 1 | 3 | 4 | 5 | 7 | 7 | 7 | 7 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 5 | 6 | 150 |
| SEDIMENTARY ROCKS, SITE INDEX 120, AGE 50 | | | | | | | | | | | | | | | | | | | |
| Test | 123 | 5 | 8 | 12 | 6 | 7 | 6 | 11 | 12 | 4 | 7 | 5 | 3 | 7 | 1 | 2 | 1 | 3 | 154 |
| Published | 149 | 1 | 3 | 5 | 7 | 7 | 8 | 8 | 9 | 8 | 8 | 7 | 7 | 7 | 6 | 5 | 3 | 1 | 150 |
| SEDIMENTARY ROCKS, SITE INDEX 130, AGE 60 | | | | | | | | | | | | | | | | | | | |
| Test | 131 | 5 | 15 | 8 | 9 | 8 | 4 | 1 | 5 | 5 | 6 | 6 | 6 | 2 | 5 | 5 | 5 | 5 | 143 |
| Published | 217 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 20 | 150 |

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# METHODS FOR REFINING GROWTH-SITE INDEX AND ENVIRONMENTAL FACTORS RELATIONSHIPS FOR LOBLOLLY PINE ON CERTAIN SOIL SERIES OF THE LOWER COASTAL PLAIN[1]

(ABSTRACT)

Marilyn A. Buford and William H. McKee, Jr.[2]

An approach to relating site productivity and environmental factors based on the assumption that the shape of the height-age profile for a site provides as much or more information about tree growth on the site than does site index value, has been implemented in the study of 105 1/4-acre plots. The plots were established in 1980 in natural loblolly pine stands on the Santee Experimental Forest in South Carolina. Soil chemical and physical analyses were performed, understory vegetation was mapped and tallied, overstory vegetation was mapped and measured, and stem analysis was performed on two dominant-condominant trees from each plot.

The goal of this analysis was to develop a methodology for quantifying the shape of the height-age profiles and for relating this shape to environmental factors. Using stem analysis data, two dominant-codominant trees from each plot were placed in site index groups with group members having equal heights at age 50. Within each site index group, height-age profile shapes developed from stem analysis were compared and departures from expected shapes were noted. Expected shapes were determined from the drainage class. Results indicate that for a given site index value, departures from expected growth patterns can be understood and predicted primarily from soil phosphorous levels for the soil series investigated. The methodology developed forms a basis for the development of a concept of tree growth and site quality relationships that is portable.

[1]Paper presented at Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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RESPONSE OF CHERRYBARK OAK FAMILIES TO

DIFFERENT SOIL-SITE CONDITIONS[1/]

Stephen G. Dicke and John R. Toliver[2/]

Abstract.--Survival and height growth in a five-year-old progeny test of cherrybark oak were studied to determine how slight differences in soils can influence performance. Cherrybark oak survival at age five decreased from 90 to 73 percent and height dropped from 9.9 to 7.3 feet respectively when the soil series changed from a somewhat poorly drained Dundee soil to a poorly drained Baldwin. Poor soil aeration reduced survival the most during year one while the major reduction in height growth rate occurred after age three. The performance of all families was worse on the poorer drained soil. However, one family was the tallest and best survivor on both soils. Therefore, both growth and tolerance to poor soil aeration can be increased by selection thereby making cherrybark oak a more viable regeneration investment in the bottomlands.

## INTRODUCTION

Cherrybark oak (Quercus falcata var pagodifolia Ell.) is the highest quality bottomland red oak in the lower Mississippi River delta region. But in 1984 cherrybark oak made up only one percent of the growing stock for this delta region (Rosson and Bertelson 1986). Therefore, the relative value of cherrybark oak should increase in the future.

Today many agronomic crops are only marginally profitable in the Delta. One alternative is conversion of these agricultural lands to high quality hardwood stands. This will normally require an artificial regeneration method such as planting. Therefore, performance of cherrybark oak needs to be evaluated in plantations before it can be recommended for reforestation.

Excessive water and poor aeration are site factors that can be detrimental to cherrybark oak growth and survival, but little is known about the magnitude of the influence. The objectives of this paper were to determine: (1) the influence of two slightly different soil series on cherrybark oak survival and height growth during the first five years of plantation development and (2) if family selection can overcome any of the negative aspects associated with poor soil drainage.

1/ Paper presented at Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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## MATERIALS AND METHODS

### Site Description

The study was located on an old field in the Thistlethwaite Game Management Area, St. Landry Parish, Louisiana. The site was a natural levee of Bayou Wauksha in the Lower Mississippi River Alluvial Floodplain. Agronomic crops had been grown on the site for approximately twenty years with soybeans being produced the year before planting.

Half of the plantation was established on the crest of the levee and the other half on the middle to lower slope away from the bayou. The levee crest was 1-2 feet higher in elevation than the lower slope thus creating differences in soils and drainage. A somewhat poorly drained Dundee soil series; a fine-silty, mixed, thermic Aeric Ochraqualf, was located on the crest of the levee (Soil Conservation Service 1986). The poorly drained Baldwin series, a fine, montmorillonitic, thermic Vertic Ochraqualf, was located on the middle to lower slope of the levee away from the bayou. Both soils had silty clay loam textures to 20 inches in depth but the Dundee had a slightly lower clay content (Faulkner 1985). This coarser texture gave the Dundee soil a faster permeability than the Baldwin, .5 verus .05 inches per hour respectively (Soil Conservation Service 1986). The Dundee soil was better

drained because of its higher topographic position and better aerated texture, whereas the Baldwin tended to pond for short periods of time after heavy rainfalls.

Faulkner (1985) found the Dundee soil to have more available water at field capacity and more extractable phosphorus than the Baldwin (Table 1). The Baldwin was better for most other soil characteristics measured. Both soils were considered good for cherrybark oak. The estimated site index at age 50 years was 99 feet for the Dundee soil and 94 feet for the Baldwin. These estimates were based on site conditions as per Baker and Broadfoot's (1979) method of site evaluation.

Table 1. Physical and chemical properties of the A and B horizons for a Dundee and Baldwin soil located in St. Landry Parish, Louisiana (From Faulkner 1985).

| | Soil horizon[1] | | | |
|---|---|---|---|---|
| | $A_p$ | | $B_2$ | |
| Soil property | Dund | Bald | Dund | Bald |
| - - - - - Physical properties - - - - - | | | | |
| Texture | SiCL[2/] | SiCL | SiCL | SiCl |
| Bulk Density (g/cc) | 1.33 | 1.27 | 1.38 | 1.31 |
| Field Capacity (%) | 32 | 33 | 32 | 35 |
| Wilting Point (%) | 16 | 19 | 20 | 23 |
| Available Water (%) | 16 | 14 | 12 | 12 |
| - - - - - Chemical Properties - - - - - | | | | |
| pH | 5.0 | 5.4 | 5.1 | 5.6 |
| Organic Matter (%) | 1.4 | 1.8 | 0.5 | 1.4 |
| Extractable P (ppm) | 63 | 22 | 107 | 15 |
| Extractable K (ppm) | 201 | 229 | 221 | 287 |
| Extractable Ca (ppm) | 3080 | 3704 | 3137 | 3845 |
| Extractable Mg (ppm) | 634 | 870 | 705 | 960 |

1/$A_p$ = plow layer (0-10 inches) and
$B_2$ = subsoil (10-20 inches).

2/SiCl = silty clay loam.

## Plantation Description

One-year-old seedlings were planted on 10-x 10-foot spacing on February 10, 1979. No site preparation was done since the site was in soybean stubble and free of weeds. Seedlings were provided by the Texas Forest Service, a cooperator in the Western Gulf Hardwood Tree Improvement Program. Twenty-four open-pollinated families from six seed sources were evaluated in this plantation. Thirteen families were from two seed sources in Arkansas, eight families were from two sources in Texas, one family was from Mississippi and two families were from a nearby stand in the Thistlethwaite Game Management Area. Weeds were controlled the first two years by discing between trees and spraying a foliar active systemic herbicide around the trees.

## Study Design and Measurements

Half of the trees were planted on the Dundee soil series while the other half were on the Baldwin. Five replications were nested within each soil. Four seedlings were planted in a row plot for each family within each replication. Seedling survival was evaluated at 1, 3, and 5 years after planting. Total height was measured at ages 3 and 5 and diameter at breast height was measured at age 5.

Differences among soils and families were tested for significance using analysis of variance at the alpha = .05 level. Means were separated using Duncan's multiple range test.

## RESULTS AND DISCUSSION

### Response to Soils

Survival

Survival averaged 82 percent at age five. Trees on the poorly drained Baldwin soil had 17 percent less survival than those on the Dundee (Table 2). This was probably a result of poorer aeration and drainage in the Baldwin. The difference in mortality rate between the two soils was the greatest the first year. Fifteen percent of the mortality on the Baldwin soil occurred the first year compared to only 6.7 percent on the Dundee. The mortality rate on both soils decreased considerably after the first year (Table 2). Therefore, poor soil aeration appeared to exert a major influence on seedling survival the first year but by age four had no significant effect.

Table 2. Mean mortality rate and survival of cherrybark oak seedlings during the first five years of plantation development on two bottomland soils in Louisiana.

| | Mortality rate by age (yrs.) | | | Survival |
|---|---|---|---|---|
| Soils | 0-1 | 2-3 | 4-5 | age 5 |
| | - - - % loss/yr - - - | | | - - % - - |
| Dundee | 6.7b[1/] | 1.6b | .10 | 90a |
| Baldwin | 15.0a | 5.7a | .21 | 73b |
| Mean | 10.8 | 3.6 | .16 | 82 |

1/Numbers in the same column followed by different letters are significantly different at alpha = .05.

Height and Diameter

Cherrybark oak averaged 8.7 feet in height and 0.83 inches in dbh at age five (Table 3). Rate of height growth on both soils was approximately the same for the first three years (1.2 feet + per year). However, after age 3, when the trees more than doubled their growth rate on both soils, the growth rate difference between the Dundee and Baldwin almost tripled. Thus, by age 5 there was a 2.6-foot difference in height between the trees on the better Dundee than those on the Baldwin soil whereas the difference was less than 0.9 foot at age 3 years.

Table 3. Mean height, height growth, and diameter of cherrybark oak during the first five years of plantation development on two bottomland soils.

| Soil | Height growth by age (yrs) 0-3 | 4-5 | Total height age 5 | DBH age 5 |
|---|---|---|---|---|
| | - ft/yr - | | - ft - | - in - |
| Dundee | 1.3a[1/] | 3.0a | 9.9a | 1.0a |
| Baldwin | 1.0b | 2.2b | 7.3b | .63b |
| Mean | 1.2 | 2.7 | 8.7 | .83 |

[1/]Numbers in the same column followed by different letters are significantly different at alpha = .05.

## Family Variation

Survival

Mean survival by family over both soils ranged from 68 to 98 percent (Table 4). The four families highest in overall survival also had 90 percent or greater survival on the Baldwin soil. One of the tallest families at age five #614 from Polk County, TX, had 95 percent survival on the poorly drained Baldwin soil. This indicates family selection can increase height growth as well as survival.

However another tall family, #619, was one of the worst families in overall survival at 68 percent (Table 4). On the Baldwin soil family 619 had only 50 percent survival. But, even 50 percent survival may have been adequate for proper stand development. Family 619 still produced 131 trees/acre greater than eight feet in height on the Baldwin soil. This was six more trees per acre than the plantation average. Thus a family with a combination of good growth and poor survival characteristics could be selected as good breeding material if that family produces a high number of large trees (potential crop trees) per acre.

Height and Diameter

Family differences were non-significant until cherrybark oak made the transition to a faster growth rate at age four. Mean heights of families at age five ranged from 10.2 to 7.1 feet and dbh ranged from 1.02 to 0.60 inches (Table 4). The four tallest families (best 15 percent) were all from Polk County, Texas. These four families averaged 10 feet in height, 0.96 inches in dbh and 83 percent survival. Dbh was not as useful as height in selection because it was a poorer measurement of stand growth. About nine percent of the trees had not yet reached 4.5 feet in height at age five.

Table 4. Mean height, dbh, and survival of cherrybark oak open-pollinated families at age five when planted on a bottomland site in southcentral Louisiana.

| Seed source State | Count parish | Family[1/] number | Height (ft) | DBH (in) | Survival (%) |
|---|---|---|---|---|---|
| AR | Bradley | 812 | 9.0 | .93 | 70 |
| | | 814 | 7.3 | .68 | 72 |
| | | 815 | 7.1 | .63 | 85 |
| | | 816 | 8.7 | .85 | 95*[2/] |
| | | 818 | 7.7 | .66 | 65 |
| | | 820 | 7.8 | .74 | 75 |
| | | 822 | 8.6 | .81 | 98* |
| AR | Clark | 317 | 8.0 | .79 | 72 |
| | | 319 | 8.7 | .91 | 85 |
| | | 323 | 8.5 | .82 | 82 |
| | | 324 | 7.8 | .60 | 82 |
| | | 325 | 8.5 | .92 | 82 |
| | | 327 | 8.4 | .90 | 90 |
| TX | Cass | 115 | 8.6 | .77 | 85 |
| | | 116 | 8.5 | .80 | 90 |
| TX | Polk | 614 | 10.0* | 1.00* | 98* |
| | | 616 | 8.8 | .77 | 80 |
| | | 618 | 8.6 | .88 | 92* |
| | | 619 | 10.0* | .97* | 68 |
| | | 620 | 10.2* | .99* | 85 |
| | | 622 | 9.9* | .90 | 82 |
| MS | Wilkinson | 411 | 9.1 | .87 | 78 |
| LA | St. Landry | 902 | 9.8 | 1.02* | 78 |
| | | 904 | 9.2 | .96 | 68 |

[1/]Family numbers assigned by the Western Gulf Hardwood Tree Improvement Program.

[2/]Values followed by an * are among the top 15 percent for that characteristic.

All families performed worse on the Baldwin soil but the best families in height on the Dundee soil were also the best on the Baldwin. The tallest four families on the Dundee were 1.5 feet greater than the average while on the

Baldwin they were 0.7 feet taller (Table 5). Therefore by selecting the top four families about one-fourth of the growth loss on the Baldwin soil could be recovered.

Table 5. Cherrybark oak height at age five for the plantation average and top 15 percent families on two bottomland soils in Louisiana.

| Soil | Total height at age 5 years | |
|---|---|---|
| | Plantation mean | Top 15 % family mean |
| | - - - - feet - - - - | |
| Dundee | 9.9 | 11.5 |
| Baldwin | 7.3 | 8.0 |
| Mean | 8.7 | 10.0 |

## CONCLUSIONS

Differences in soil drainage and aeration exerted a strong influence on early cherrybark oak survival and growth. Mortality rate was doubled on a poorer drained Baldwin soil compared to a Dundee soil. Most of the mortality was during the first growing season. Height growth was similar on both soils for the first three years, but during years four and five, height growth was one-third less on the Baldwin soil. Thus, by age five, trees on the better Dundee soil were 25 percent taller.

Although there was a loss of 2.6 feet in height when the trees were grown on the Baldwin soil about one-fourth of this growth could be recovered by selecting the best four families. Family selection for survival showed even more promise, since several families had 90 percent survival on the poorly drained Baldwin soil. One family was the best in both height and survival. Therefore both traits could be improved together through family selection.

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## Silviculture-Economic Relationships

Moderator:

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# Production and Financial Comparisons of Uneven-aged and Even-aged Management of Loblolly Pine[1]

James B. Baker[2]

Abstract.--Production and financial comparisons were made of two even-aged and two uneven-aged loblolly pine (Pinus taeda L.) management systems. In terms of production, the even-aged systems--plantation and natural stand management--produced the most cubic-foot volume, while uneven-aged management with high stocking levels and even-aged plantation management produced the most sawlog volume. From a financial standpoint, even-aged natural stand management generally showed a distinct advantage over the other three management systems, surpassing them in net present value, benefit-to-cost ratio, and cost efficiency of cubic-foot production. Uneven-aged management with high stocking levels was the most efficient system in terms of sawlog production.

## INTRODUCTION

Past research has demonstrated that loblolly pine (Pinus taeda L.) can be regenerated and managed under a variety of silvicultural systems ranging from uneven-aged (selection) management to intensive plantation culture. But the question is often asked, "Which is the best management system?" The answer, of course, depends on the objectives of the landowner. If the sole purpose of land management is the production of merchantable timber products and/or income, then production and financial analyses are required. If the purpose of land management includes other amenities, such as wildlife, water, recreation, or aesthetics, then the values of these amenities must be considered.

Production and financial comparisons of four loblolly pine management systems on average sites (site index = 90 feet at 50 years) for the mid-South are provided in this paper.

[1]Paper presented at Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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## METHODS

Production and financial comparisons for three of the management systems--even-aged natural stand and plantation management, and uneven-aged management with high stocking levels--were based on case studies that have been conducted on or near the Crossett Experimental Forest in southeastern Arkansas. The comparison for the fourth management system was based on a simulation of uneven-aged management with reduced stocking levels.

The comparisons were made assuming that all four management systems could have been initiated on identical 40-acre tracts of land and managed for a 50-year period. The management systems included two uneven-aged and two even-aged management options. The uneven-aged options represented management with low and high stocking levels, while the even-aged options represented even-aged natural stand management and plantation management. The simulations assumed the following initial stand characteristics:

- -- 85 merchantable pines (4 inches d.b.h. and larger) per acre.
- -- 18 sawlog size trees (12 inches d.b.h. and larger) per acre.
- -- 36 square feet of pine basal area per acre.
- -- 980 cubic feet of total merchantable volume per acre.
- -- 2,341 board feet (Doyle)[3] sawlog volume per acre.

[3]All board-foot volumes in this paper are in Doyle scale.

For the two uneven-aged systems, the initial stand was to be managed under the selection system. Growing stock was improved to prescribed (low or high) levels, and the stand was harvested on a 5-year cutting cycle.

For the even-aged natural stand system, the initial stand was assumed to be a shelterwood having adequate pine regeneration established in the understory. The overstory (2,341 board feet per acre plus all pulpwood) was harvested at the beginning of the management period. The regenerated stand was thinned periodically and clearcut at the end of the 50-year period.

For the even-aged plantation, the initial overstory (2,341 board feet per acre plus all pulpwood) was clearcut at the beginning of the management period. The site was prepared and planted to loblolly pine. The stand was thinned periodically and clearcut at the end of the 50-year period.

A summary of the four management scenarios are presented below.

Uneven-aged management schemes:

(1) Building and maintaining an uneven-aged stand at a relatively high stocking level--9,000 board feet of sawlog volume immediately before 5-year cyclic harvest cuts. Production and harvest volumes for the first 40 years of management are from the "Poor Farm Forty" on the Crossett Experimental Forest (Reynolds and others 1984). Values for the last 10 years of management were projected based on recent periodic increments of the stand.

(2) Building and maintaining an uneven-aged stand at a relatively low stocking level--7,000 board feet of sawlog volume immediately before 5-year cyclic harvest cuts. Estimates of production and harvest volumes were generated using a growth and yield model for uneven-aged stands (Farrar and others 1984). This scenario allowed for an initially understocked stand to reach a prescribed full stocking level sooner than the other uneven-aged management scheme, above, and to carry a lower growing stock volume (or investment) throughout the management period.

Even-aged management schemes:

(1) Management of a stand that originated from natural reproduction obtained from a shelterwood reproduction cutting method. The overstory (2,341 board feet of pine sawlogs plus all pulpwood) was removed at the beginning of the management period. The regenerated stand was thinned to 85 square feet of basal area per acre at 5-year intervals beginning at age 20. Production and harvest volumes were obtained from a thinned 50-year-old natural stand that had been subjected to these treatments (Burton 1980, Murphy and Farrar 1985).

(2) Management of a pine plantation established after clearcutting the 2,341 board feet of sawlogs per acre plus all pulpwood at the beginning of the management period, followed by site preparation and planting. The stand was thinned to 85 square feet basal area per acre at 5-year intervals beginning at age 15. Values for production and harvest volumes were obtained from a thinned 50-year-old plantation that had been subjected to these treatments[4].

## RESULTS

### Timber Production

A summary of stand development, harvest cuts, and timber production for the four management systems over the 50-year management period is presented in tables 1 through 4, and timber production for the four systems is summarized in table 5.

For these case studies, plantation management produced 9 percent more total merchantable cubic-foot volume per acre than even-aged natural stand management, 44 percent more than uneven-aged management with high stocking, and 107 percent more than uneven-aged management with low stocking (table 5). In terms of pulpwood or fiber production, even-aged management was clearly superior to the uneven-aged systems.

In terms of sawlog production, both uneven-aged management with high stocking and plantation management produced about 25 percent more board-foot volume per acre than either uneven-aged management with low stocking or even-aged natural stand management (table 5). Uneven-aged management with high stocking levels and plantation management averaged about 420 board feet per acre per year of sawlog growth, while uneven-aged management with low stocking and even-aged natural stand management averaged only about 340 board feet. Thus, uneven-aged management with high stocking levels and plantation management appeared to be superior for sawlog production.

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[4]Data on file at the Forestry Sciences Laboratory, USDA--Forest Service, Southern Forest Experiment Station, Monticello, AR 71655.

Table 1. Characteristics, harvests, and timber production for an uneven-aged loblolly pine stand with high stocking levels over a 50-year management period

| Time | Before Harvest | | | Harvest | | | Residual Stand | | |
|---|---|---|---|---|---|---|---|---|---|
| | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) |
| years | - - - - - - - | - - - - - - - | - - - - - - - | - - - - - - - | per acre | - - - - - - - | - - - - - - - | - - - - - - - | - - - - - - - |
| 0 | 36 | 980 | 2,341 | -- | --- | --- | 36 | 980 | 2,341 |
| 5 | 49 | 1,214 | 3,135 | 10 | 248 | 1,017 | 39 | 966 | 2,118 |
| 10 | 53 | 1,179 | 3,701 | 13 | 252 | 1,060 | 40 | 927 | 2,641 |
| 15 | 57 | 1,501 | 4,583 | 9 | 283 | 1,204 | 48 | 1,218 | 3,379 |
| 20 | 64 | 1,408 | 4,339 | 10 | 340 | 1,410 | 54 | 1,068 | 2,929 |
| 25 | 70 | 1,863 | 5,304 | 15 | 417 | 1,598 | 55 | 1,447 | 3,706 |
| 30 | 75 | 1,952 | 4,982 | 18 | 490 | 1,878 | 57 | 1,462 | 3,104 |
| 35 | 80 | 1,957 | 5,323 | 20 | 556 | 1,935 | 60 | 1,401 | 3,388 |
| 40 | 85 | 2,303 | 7,277 | 25 | 611 | 2,046 | 60 | 1,692 | 5,231 |
| 45 | 75 | 2,393 | 8,969 | 15 | 637 | 2,046 | 60 | 1,756 | 6,923 |
| 50 | 75 | 3,043 | 9,388 | 15 | 650 | 2,047 | 60 | 2,393 | 7,341 |
| Residual | 60 | 2,393 | 7,341 | | | | | | |
| Increase | 24 | 1,413 | 5,000 | | | | | | |
| Harvest | | | | 150 | 4,484 | 16,241 | | | |
| Yield | | | | 174 | 5,897 | 21,241 | | | |
| Periodic annual increment | | | | 3.5 | 118 | 425 | | | |

Table 2. Characteristics, harvests, and timber production for an uneven-aged loblolly pine stand with low stocking levels over a 50-year management period

| Time | Before Harvest | | | Harvest | | | Residual Stand | | |
|---|---|---|---|---|---|---|---|---|---|
| | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) |
| years | - - - - - - - | - - - - - - - | - - - - - - - | - - - - - - - | per acre | - - - - - - - | - - - - - - - | - - - - - - - | - - - - - - - |
| 0 | 36 | 980 | 2,341 | -- | --- | --- | 36 | 980 | 2,341 |
| 5 | 49 | 1,333 | 3,721 | 9 | 245 | 1,014 | 40 | 1,088 | 2,707 |
| 10 | 53 | 1,461 | 4,178 | 9 | 248 | 1,056 | 44 | 1,213 | 3,122 |
| 15 | 58 | 1,603 | 4,705 | 9 | 250 | 1,042 | 49 | 1,353 | 3,663 |
| 20 | 64 | 1,759 | 5,369 | 9 | 252 | 1,093 | 55 | 1,507 | 4,276 |
| 25 | 70 | 1,928 | 6,103 | 10 | 281 | 1,204 | 60 | 1,647 | 4,899 |
| 30 | 75 | 2,079 | 6,826 | 15 | 432 | 1,802 | 60 | 1,647 | 5,024 |
| 35 | 75 | 2,079 | 6,960 | 15 | 432 | 1,935 | 60 | 1,647 | 5,025 |
| 40 | 75 | 2,079 | 6,960 | 15 | 432 | 1,935 | 60 | 1,647 | 5,025 |
| 45 | 75 | 2,079 | 6,960 | 15 | 432 | 1,935 | 60 | 1,647 | 5,025 |
| 50 | 75 | 2,079 | 6,960 | 15 | 432 | 1,935 | 60 | 1,647 | 5,025 |
| Residual | 60 | 1,647 | 5,025 | | | | | | |
| Increase | 24 | 667 | 2,684 | | | | | | |
| Harvest | | | | 121 | 3,436 | 14,951 | | | |
| Yield | | | | 145 | 4,103 | 17,635 | | | |
| Periodic annual increment | | | | 2.9 | 82 | 352 | | | |

Table 3. Characteristics, harvests, and timber production for an even-aged natural loblolly pine stand over a 50-year management period

| | Before Harvest | | | Harvest | | | Residual Stand | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) |
| years | - - - - - - | - - - - - - | - - - - - - | - - - - - - | per acre | - - - - - - | - - - - - - | - - - - - - | - - - - - - |
| 0 | 36 | 980 | 2,341 | 36 | 980 | 2,341 | -- | --- | --- |
| 5 | -- | --- | --- | -- | --- | --- | -- | --- | --- |
| 10 | -- | --- | --- | -- | --- | --- | -- | --- | --- |
| 15 | -- | --- | --- | -- | --- | --- | -- | --- | --- |
| 20 | 147 | 1,800 | 460 | 62 | 652 | --- | 85 | 1,148 | 460 |
| 25 | 115 | 2,173 | 2,291 | 30 | 535 | --- | 85 | 1,638 | 2,291 |
| 30 | 117 | 2,466 | 2,887 | 31 | 508 | 1,022 | 86 | 1,958 | 1,865 |
| 35 | 111 | 3,178 | 7,050 | 26 | 710 | 1,593 | 85 | 2,468 | 5,457 |
| 40 | 106 | 3,561 | 9,593 | 21 | 684 | 1,210 | 85 | 2,877 | 8,383 |
| 45 | 96 | 3,310 | 9,300 | 11 | 1,093 | 927 | 85 | 2,217 | 8,373 |
| 50 | 100 | 3,625 | 11,662 | 100 | 3,625 | 11,662 | -- | --- | --- |
| Residual | 0 | 0 | 0 | | | | | | |
| Harvest | | | | 317 | 8,787 | 18,755 | | | |
| Yield | | | | 281 | 7,807 | 16,414 | | | |
| Mean annual increment | | | | 5.6 | 156 | 328 | | | |

Table 4. Characteristics, harvests, and timber production for an even-aged loblolly pine stand plantation over a 50-year management period

| | Before Harvest | | | Harvest | | | Residual Stand | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) | Basal area ($ft^2$) | Total merch. ($ft^3$) | Board-feet (Doyle) |
| years | - - - - - - | - - - - - - | - - - - - - | - - - - - - | per acre | - - - - - - | - - - - - - | - - - - - - | - - - - - - |
| 0 | 36 | 980 | 2,341 | 36 | 980 | 2,341 | -- | --- | --- |
| 5 | -- | --- | --- | -- | --- | --- | -- | --- | --- |
| 10 | -- | --- | --- | -- | --- | --- | -- | --- | --- |
| 15 | 120 | 2,071 | --- | 35 | 400 | --- | 85 | 1,671 | --- |
| 20 | 125 | 2,521 | 1,520 | 40 | 576 | --- | 85 | 1,944 | 1,520 |
| 25 | 125 | 2,794 | 3,910 | 40 | 728 | --- | 85 | 2,066 | 3,910 |
| 30 | 110 | 2,916 | 5,980 | 25 | 96 | 1,124 | 85 | 2,820 | 4,856 |
| 35 | 103 | 3,670 | 8,100 | 18 | 1,392 | 1,314 | 85 | 2,278 | 6,786 |
| 40 | 105 | 3,270 | 10,390 | 20 | 1,152 | 3,262 | 85 | 2,118 | 7,128 |
| 45 | 100 | 2,843 | 11,238 | 15 | 688 | 2,438 | 85 | 2,155 | 8,800 |
| 50 | 100 | 3,456 | 12,818 | 100 | 3,456 | 12,818 | -- | --- | --- |
| Residual | 0 | 0 | 0 | | | | | | |
| Harvest | | | | 329 | 9,468 | 23,297 | | | |
| Yield | | | | 293 | 8,488 | 20,956 | | | |
| Mean annual increment | | | | 5.9 | 170 | 419 | | | |

Table 5.--Summary of total and mean annual production of loblolly pine for four management systems over a 50-year management-period

| Management system[1] | Production per acre | | | |
|---|---|---|---|---|
| | Total | | Mean annual | |
| | Tot. merch. cubic feet | Board feet (Doyle) | Tot. merch. cubic feet | Board feet (Doyle) |
| Uneven-aged (HS) | 5,897 | 21,241 | 118 | 425 |
| Uneven-aged (LS) | 4,106 | 17,618 | 82 | 352 |
| Even-aged (Natural) | 7,807 | 16,414 | 156 | 328 |
| Even-aged (Plantation) | 8,488 | 20,956 | 170 | 419 |

[1] HS = high stocking; LS = low stocking.

## Financial Analyses

Three different financial analyses were performed for each of the management systems, using the production values presented in tables 1 through 4 and the following cost and return assumptions:

Costs:

(1) Selection management
- (a) Annual management costs = $2 per acre
- (b) Supplemental management cost (inventory & marking) = $13 per acre every 5 years (prior to harvest cut)
- (c) Timber stand improvement (TSI) = $45 per acre applied every 10 years

(2) Natural even-aged management
- (a) Annual management costs = $2 per acre
- (b) Initial TSI = $45 per acre
- (c) Pine release at age 5 = $45 per acre
- (d) Prescribed burning = $5 per acre every 5 years beginning at age 15
- (e) Supplemental management cost (inventory & marking) = $13 per acre every 5 years beginning at age 20

(3) Plantation management
- (a) Annual management costs = $2 per acre
- (b) Site preparation and planting = $150 per acre
- (c) Pine release at age 5 = $45 per acre
- (d) Prescribed burning = $5 per acre every 5 years beginning at age 15
- (e) Supplemental management cost (inventory & marking) = $12 per acre every 5 years beginning at age 15

Returns:

(1) Pulpwood stumpage = $15 per cord
(2) Sawlog stumpage = $150 per thousand board feet (Doyle)

Discount Rate: 7 percent compounded annually

The methods used for the analyses were:

(1) Net Present Value (NPV) -- The sum of all returns anticipated from a management system, discounted back to the present, minus the sum of all anticipated costs, also discounted to the present. It represents the present value of the profit associated with the system after repaying all capital and interest expenses. Net present value is an appropriate analysis in cases were investment capital is not particularly limiting or in comparing investments of approximately equal size. It is frequently used by forest industry firms.

(2) Benefit-to-Cost Ratio (B-C) -- The discounted value of all returns anticipated from a management system divided by the discounted value of all anticipated costs. Thus B-C represents the present value of the return per dollar invested in the system, or its economic efficiency. It is appropriate in cases where capital is limiting, as for example with private nonindustrial landowners, or in comparing investments of unequal amount.

(3) Cost Efficiency -- The output or yield expected from a management system divided by the discounted value of all costs associated with the system. Since it estimates physical output per dollar invested in the system, cost efficiency can be considered a physical analog of B-C. Cost efficiency is most appropriate in cases where the owner wishes to maximize yield of a particular product, for example sawtimber, or where the

product carries no readily identifiable dollar value.

A summary of the financial analyses is given in table 6.

Over the 50-year management period, the even-aged systems had a more favorable NPV at \$493 to \$541 per acre than the uneven-aged systems at \$314 to \$404 per acre. In terms of B-C ratios, even-aged natural stand management had the advantage due to its low management cost with a ratio of 5.4:1. Uneven-aged management with low stocking levels and even-aged plantation management provided the lowest B-C ratio (3.1:1), while uneven-aged management with high stocking levels was intermediate with a ratio of 3.7:1.

When cost efficiency was considered, even-aged natural stand management was more efficient in terms of total merchantable cubic-foot production with about 64 cubic feet produced per dollar spent. In terms of sawlog production, however, the selection system with high stocking levels was the most efficient, with 143 board feet produced per dollar spent. Plantation management and uneven-aged management with low stocking levels were the poorest systems in terms of cost efficiency.

## SUMMARY AND CONCLUSIONS

Production comparisons of two even-aged and two uneven-aged management systems for loblolly pine over a 50-year management period indicated that plantation management maximizes total merchantable cubic-foot volume production. The greatest amount of sawlog volume was produced using either uneven-aged management with high stocking levels or plantation management.

In financial comparisons, the two even-aged systems had the most favorable NPV, although at very different investment levels. Even-aged natural stand management had by far the best B-C ratio and the highest cost efficiency for fiber (cubic-foot) production, while uneven-aged management with high stocking levels had the highest cost efficiency for sawlog production. Where the landowner desires the best possible economic efficiency, investing in the management system with the highest B-C ratio would be financially best. Where the owner desired to produce a particular output, or product, he should select the system with the highest cost efficiency for that product.[5]

The high NPV for even-aged plantation management is misleading in that it resulted more from the relatively large investment required by the system than from its efficiency. The results of this comparison indicate that a landowner should select this system only if he desires one of the noneconomic benefits associated with it--such as maximum total output or production, the opportunity to plant superior seedling, or ease of management.[6]

A landowner who used a management system with a high efficiency measure, such as B-C ratio or cost efficiency, could manage a larger land base with the same investment or the same land base with a smaller investment. For example, even-aged natural stand management and uneven-aged management with high stocking levels both have very favorable B-C ratios. These combined with the systems' high cost efficiency values for either cubic-foot or sawlog production suggest that many landowners could enjoy cost savings by managing existing stands rather than engaging in extensive conversion to plantation culture.

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[5]Personal communication with R. A. Guldin, Forest Economist, Southern Forest Experiment Station, New Orleans, LA.

[6]Personal communication with John Greene, Professor of Forest Economics and Policy, Dept. of Forest Resources, University of Arkansas at Monticello, Monticello, AR.

Table 6. Four loblolly pine management system economic parameters for a 50-year management period at a 7 percent discount rate

| Management system[1] | Net present value | Benefit-to-cost ratio | Cost efficiency[2] ($ft^3$) | Cost efficiency[2] (fbm) |
|---|---|---|---|---|
| | dollar/acre | | ----per dollar---- | |
| Uneven-aged (HS) | 404 | 3.71 | 39.6 | 142.6 |
| Uneven-aged (LS) | 314 | 3.11 | 27.6 | 118.2 |
| Even-aged (Natural) | 541 | 5.40 | 63.5 | 133.4 |
| Even-aged (Plantation) | 493 | 3.13 | 36.7 | 90.7 |

[1] HS = high stocking; LS = low stocking.
[2] Cost efficiency = total production/total discounted cost.

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ECONOMIC ASSESSMENT OF CHEMICAL VERSUS

MECHANICAL SITE PREPARATION[1]

Clifford A. Hickman, Walter C. Anderson, and Richard W. Guldin[2]

Abstract.--The economics of chemical site preparation relative to three intensities of mechanical site preparation were evaluated for a variety of site conditions. Specifically, the investment returns obtainable from unthinned loblolly pine plantations grown over rotations of 20, 25, and 30 years were estimated and compared for all combinations of treatment method and site condition. Chemical site preparation proved to be the most cost-effective technique when the residual hardwood stocking was moderate to heavy and the "best" or "expected" treatment outcomes were presumed to occur. Where there was little or no hardwood competition, the heavy mechanical procedure was superior. This technique also gave the highest returns for all site conditions envisioned when the "worst" treatment outcomes were assumed.

Keywords: Hexazinone, cost effectiveness, loblolly pine.

The 1979 Timber Assessment concluded that the Nation's greatest opportunities for increasing timber growth are located in the South (USDA 1982). The region contains as many as 52.1 million acres of existing stands, which -- because they are either at or past maturity, or suffer from poor species composition -- would benefit from conversion to young, vigorous pine plantations (Dutrow and Kaiser 1984). Experience has shown, however, that it will not be easy to capitalize on these investment opportunities. On cutover areas of the type envisioned, large expenditures for site preparation may be needed to ensure adequate control of the inevitable competition from both hardwood sprouts and herbaceous weeds.

Competing vegetation in pine plantations has traditionally been controlled by fire, mechanical means, or both procedures combined. These alternatives, however, have not proved totally satisfactory. Use of fire is limited by weather conditions, and hardwood brush is sometimes poorly controlled (Kushmaul 1978). Use of mechanical means tends to be expensive, and significant site disturbance sometimes results (Guldin 1983a; Kushmaul 1978). Because of these deficiencies, chemical site preparation has been the object of considerable attention in recent years. Research has clearly shown that chemicals, when properly applied, are capable of providing effective competition control (Glover and Dickens 1986). Less clear is how herbicides compare to other treatment options from an economic standpoint.

The objective of this study was to evaluate the economics of using chemical as opposed to mechanical means to prepare cutover sites for planting. The analysis was conducted under the premise that hexazinone, trade name Velpar®, would be the specific chemical used.[3] However, because our current understanding of the relative effectiveness of various site preparation herbicides does not allow us to accurately distinguish between them, the results are probably indicative of how chemical treatments in general compare to mechanical procedures.

## APPROACH

The evaluation was structured around three basic steps. First, a broad range of possible treatment opportunities -- i.e., site conditions -- were hypothesized. Secondly, a series of alternative treatment options -- i.e., site preparation methods -- were defined. Finally, investment returns were calculated for all treatment opportunity and treatment option combinations. These returns were predicated on the assumption that loblolly pine (Pinus taeda L.) plantations, established at an initial density of 700 trees per acre, would be grown unthinned over rotations of 20, 25, or 30 years.

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[3] Trade names are used for the reader's information and convenience. Their use in this study does not constitute official endorsement or approval by the U.S. Department of Agriculture to the exclusion of other suitable products.

## Treatment Opportunities

The treatment opportunities that were recognized in the analysis consisted of all combinations of three post-harvest residual hardwood stocking levels and three site productivity classes. The three possible post-harvest residual hardwood stocking levels were:

- Light: 10 percent of the preceding stand's total basal area (BA) in unmerchantable hardwoods.
- Moderate: 30 percent of the preceding stand's total BA in unmerchantable hardwoods.
- Heavy: 50 percent of the preceding stand's total BA in unmerchantable hardwoods.

The three site productivity classes corresponded to site indicies of 50, 60, and 70 feet at a base age of 25 years.

## Treatment Options

The treatment options that were recognized in the analysis consisted of three intensities of mechanical treatment and one intensity of chemical treatment. The specific treatment methods and their associated site preparation practices were:

- Light mechanical: chop and burn.
- Moderate mechanical: shear, pile, and burn piles.
- Heavy mechanical: shear, pile, burn piles, and disk.
- Chemical: aerial application of hexazinone at label rates followed by burning.

## Calculation of Investment Returns

The investment returns that would be obtained, given each combination of treatment opportunity and method, were estimated using a computer model called ECONHDWD.[4] This model predicts the survival, growth, and yield of unthinned loblolly pine plantations under various levels of hardwood competition and transforms the projected outputs into measures of economic performance. Although the program will do investment analyses in either real or current value terms, for purposes of this study the real value method was employed. In addition, of the several decision criteria the model computes, only the internal rate of return (IRR) was considered.

To utilize ECONHDWD, several types of input data were required. Specifically, for each combination of treatment method and treatment opportunity, it was necessary to provide estimates of (1) the proportion of each plantation's total BA that would be in hardwoods at the time of crown closure; (2) the site preparation, planting, and other management costs that would be incurred; and (3) the stumpage prices that would be received at harvest for both sawtimber and pulpwood products. Of these data requirements, the first was by far the most difficult to satisfy.

### Basal Area Percentages

The desired BA percentages were derived through a four step process, each component of which merits explanation, as follows:

Step 1. -- To estimate, for each of the hypothesized treatment opportunities, how many square feet of hardwood BA would be left on site following removal of the preceding stand. This was accomplished by multiplying the pre-assigned residual hardwood stocking proportions for each site -- i.e., 10, 30, or 50 percent -- by a corresponding set of expected total BA's. The latter were determined with the aid of data from Schumacher and Coile (1960).[5]

Step 2. -- To estimate, for each of the hypothesized treatment opportunities, how many square feet of hardwood BA would be left on site following application of specific site preparation procedures. This was accomplished by constructing -- based on published research findings as well as expert opinion -- the subjective probability distributions shown in table 1. These distributions define the assumed levels of hardwood control that would result from using each of the treatment options being recognized in the study.[6] The distributions were employed to specify three of the many possible outcomes that could conceivably result from application of a particular site preparation technique to a particular site. These outcomes were designated as the "worst" -- i.e., least favorable; "expected" -- i.e., most likely; and "best" -- i.e., most favorable.[7]

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[4] Sprinz, Peter T.; Burkhart, Harold E.; Greber, Brian J. A model for the economic assessment of reducing hardwood competition in loblolly pine plantations. (mimeographed). No date. [Available from Department of Forest Science, Texas A&M University, College Station, TX].

[5] Schumacher and Coile data were used to ascertain, for sites in each of the assumed productivity classes, how many square feet of BA would occur in a 35-year-old fully-stocked natural stand of loblolly pine. These preliminary figures were then adjusted to account for the fact that total BA would probably decline as the proportion of the stand in hardwoods increased. Per acre reductions were made at the rate of 1.18 $ft^2$ for each percentage point increase in the hardwood component.

[6] The probabilities of non-control, which were the actual values needed, were determined by deducting the probabilities of control from 1.0.

[7] For each site preparation procedure, the "expected" outcome was computed by (1) multiplying the potential levels of hardwood control by their corresponding probabilities of occurrence and (2) aggregating the products. The "best" and "worst" outcomes, as their names imply, corresponded to the upper and lower tails of the various probability distributions.

Table 1. -- Effectiveness of alternative site preparation methods in controlling hardwoods

| Treatment method | Hardwoods controlled (percent) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
| | - - - - - - - - - - - - - (probability of occurrence) - - - - - - - - - - - - - | | | | | | | | | | | | | | | | | | | | |
| Mechanical | | | | | | | | | | | | | | | | | | | | | |
| Light | | | | | | | .05 | .05 | .10 | .15 | .30 | .15 | .10 | .05 | .05 | | | | | | |
| Moderate | | | | | | | | | | | | .05 | .10 | .15 | .40 | .15 | .10 | .05 | | | |
| Heavy | | | | | | | | | | | | | | | .05 | .05 | .10 | .30 | .35 | .15 | |
| Chemical (hexazinone) | | | | | | | | | | | | .02 | .04 | .06 | .08 | .10 | .14 | .30 | .14 | .08 | .04 |

Step 3. -- To develop, for each combination of treatment method and opportunity, preliminary estimates of the proportions of total plantation BA that would be in hardwoods at the time of crown closure. This was accomplished by expressing the BA figures from step 2 as percentages of the total BA's that the plantations were expected to have at age 10, an assumed proxy for the time of crown closure.[8] The latter were estimated with the aid of a growth and yield model called USLYCOWG (Feduccia and others 1979).

Step 4. -- Finally, to distribute the preliminary BA percentages developed in step 3 to a selected group of scientists who have been engaged in vegetative control research for evaluation. Based on the responses obtained, some of the initial figures were adjusted, thereby giving rise to the final estimates shown in table 2. Note that in constructing this table, weighted averages of the BA percentages for site 50, 60, and 70 lands were computed. The weights used in this averaging process were .20, .75, and .05, respectively. These weights reflect, for the Midsouth, the acreage distribution of loblolly pine stands by site productivity class (Feduccia and others 1979).

Table 2. -- Proportion of hardwood basal area in plantation[1] at age 10 for worst, best, and expected treatment outcomes, by treatment method and opportunity

| Treatment method | Treatment opportunity and outcome | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Light residual hardwoods | | | Moderate residual hardwoods | | | Heavy residual hardwoods | | |
| | Worst | Expected | Best | Worst | Expected | Best | Worst | Expected | Best |
| | - - - - - - - - - - - - - - - (percent hardwood) - - - - - - - - - - - - - - - | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | 13 | 9 | 5 | 31 | 22 | 13 | 39 | 28 | 17 |
| Moderate | 8 | 5 | 3 | 20 | 13 | 7 | 25 | 17 | 8 |
| Heavy | 5 | 2 | 1 | 13 | 6 | 2 | 17 | 8 | 3 |
| Chemical (hexazinone) | 9 | 4 | 1 | 22 | 10 | 2 | 28 | 13 | 3 |

[1]Based on 700 trees planted per acre.

## Management Costs

The site preparation costs that were used in the study are shown in table 3. The costs of mechanical site preparation were compiled using data from

[8]Though this approach makes sense mathematically, in reality its reasonableness is uncertain. When an area is site-prepared, at least by mechanical means, the BA of uncontrolled hardwoods will drop to essentially nothing immediately after treatment. Sometime later a hardwood component may emerge in the new stand through resprouting, but the nature of the relationship, if any, between the BA of these sprouts and the hardwood BA that existed before treatment is unclear. The number and distribution of the former stems is probably more important than their BA.

Table 3. -- Site preparation costs, by treatment method and opportunity

| Treatment method | Treatment opportunity | | |
|---|---|---|---|
| | Light residual hardwoods | Moderate residual hardwoods | Heavy residual hardwoods |
| | - - - - - - - - | (dollars/acre) | - - - - - - - - |
| Mechanical | | | |
| Light | 55.00 | 65.00 | 80.00 |
| Moderate | 75.00 | 100.00 | 140.00 |
| Heavy | 80.00 | 155.00 | 215.00 |
| Chemical (hexazinone) | 90.00 | 90.00 | 90.00 |

Straka and Watson (1985), Guldin (1983a), and Fitzgerald (1985); the costs of chemical site preparation were determined by contacting several firms engaged in the aerial application of hexazinone; and the costs of burning were obtained, once again, from Straka and Watson (1985). Note that the costs of the mechanical treatments, unlike those of the chemical treatment, were allowed to vary with the assumed level of residual hardwood stocking. The costs of the chemical treatment were held constant because on coarse soils, such as the sandy loams where loblolly pine is typically grown, the recommended application rate for hexazinone (2 gallons, or 4 pounds of active ingredient per acre) does not change with the volume of hardwoods occupying the site.

The planting costs that were used in the study are shown in table 4. Planting costs, exclusive of seedlings, were taken from Straka and Watson (1985) and Guldin (1983b). It was assumed that these costs would vary with the amount of woody vegetation remaining on the site at the time of planting. Seedling costs, which as noted earlier were based on an assumed planting density of 700 trees per acre, were set at $17.50 per acre. This value was derived by using data from both Guldin (1983b) and the most recent seedling cost survey published in Forest Farmer magazine (Forest Farmers Association 1985).

The only other expenditure that was recognized in the analysis was an annual administrative expense of $3.50 per acre. This amount was intended to reflect the costs of such things as property taxes; boundary maintenance; road maintenance; and fire, insect, and disease control.

Stumpage Prices

On the income side of the ledger, stumpage prices for the two types of timber outputs that were recognized in the study -- i.e., sawtimber and pulpwood -- were taken from Timber Mart

Table 4. -- Planting costs[1], by treatment method and opportunity.

| Treatment method | Treatment opportunity | | |
|---|---|---|---|
| | Light residual hardwoods | Moderate residual hardwoods | Heavy residual hardwoods |
| | - - - - - - - - | (dollars/acre) | - - - - - - - - |
| Mechanical | | | |
| Light | 52.50 | 67.50 | 77.50 |
| Moderate | 52.50 | 67.50 | 67.50 |
| Heavy | 52.50 | 52.50 | 67.50 |
| Chemical (hexazinone) | 52.50 | 67.50 | 77.50 |

[1]Includes $17.50/acre for seedlings.

South.[9] Sawtimber was valued at $150.00 per thousand board feet (Scribner). Pulpwood was valued at $17.00 per standard cord. To ensure consistency throughout the analysis, all prices and costs were expressed in terms of constant 1984 dollars. Furthermore, no real cost or price changes were considered in projecting future receipts and expenditures.

## RESULTS

The data generated by the study comprised a set of 324 IRR figures. These figures showed the estimated investment returns associated with each combination of the nine treatment opportunities, four treatment methods, three treatment outcomes, and three rotation lengths that were recognized in the analysis. Although these values could have been employed to evaluate the mechanical techniques relative to one another, or to determine under what conditions site preparation is profitable, they were used only to draw comparisons between the various mechanical options and the chemical option.

Because the choice of a site preparation procedure is often made on the basis of the amount of hardwood competition to be controlled, the study results are presented by treatment opportunity.

### Light Residual Hardwood Stocking

On sites where the residual hardwood stocking was no more than 10 percent of the preceding stand's total BA, the chemical treatment was either inferior to, or at least no better than, the mechanical site preparation techniques (table 5). This relationship was consistent over all the treatment outcome, site index, and rotation age combinations evaluated. The principal reason for the relatively poor showing of the chemical option seems to be that this procedure, as defined for purposes of this study, has no cost advantage over the mechanical means when applied to such sites. Indeed, as a review of tables 3 and 4 shows, if the residual hardwood stocking is light -- use of hexazinone is the most expensive practice that can be employed.

### Moderate Residual Hardwood Stocking

On areas where the residual hardwood stocking was no more than 30 percent of the preceding stand's total BA, broadcast applications of hexazinone were the most profitable method of site preparation as long as the "expected" or "best" treatment outcomes were presumed to occur. This relationship was consistent over all the site index and rotation age combinations evaluated (table 6). However, when it was assumed that the "worst" treatment outcomes would materialize, the heavy mechanical option emerged as the preferred method of treatment. The relatively poorer showing of the chemical alternative in this worst case scenario is directly traceable to the greater uncertainties that were assumed to be associated with this procedure. As was shown in table 1, if it is presumed that the "worst" possible outcomes will occur, the implication is that the application of chemicals will control only 50 percent of the hardwoods on the site to be treated.

### Heavy Residual Hardwood Stocking

Turning finally to sites where the residual hardwood stocking was as much as 50 percent of the preceding stand's total BA, the results were essentially identical to those for the moderate residual hardwood case (table 7). When it was assumed that the "expected" or "best" treatment outcomes would occur, the broadcast application of hexazinone was the most profitable site preparation practice for all combinations of site index and rotation length.[10] This is largely attributable to the substantial cost advantages that this method of treatment has over all but the light mechanical treatment when applied to such sites (see tables 3 and 4). When the "worst" possible outcomes were presumed to materialize, the heavy mechanical technique was once again the most suitable site preparation procedure. As before, the worst case scenario's relatively unfavorable ranking of the chemical option is traceable to the greater uncertainty that was assumed to be associated with this alternative.

### Conclusions

The results of this analysis suggest that the aerial application of hexazinone at label rates will normally be the most cost effective way of preparing cutover sites with a moderate or heavy residual stocking of hardwoods. On sites where there is little hardwood competition, mechanical methods should usually be employed. The principal exceptions to these generalizations occur under the relatively pessimistic assumptions of the worst case scenario. In these instances, the heavy mechanical technique, because of its dependable effectiveness, is typically the preferred procedure.

## DISCUSSION

The preceding findings, for at least two reasons, must be interpreted and acted upon with caution. The first reason pertains to the limited

[9] Published monthly by F. W. Norris; P. O. Box 1278; Highlands, NC 28741.

[10] As a point of clarification, for any investment to be judged worthwhile, including those involving site preparation activities, it is not sufficient that the returns be positive -- they must also exceed the investor's "cost of capital." The latter is generally determined by either (1) the rate of earnings obtainable from the next best use of the investor's funds or (2) the rate at which the investor can borrow.

Table 5. -- Rates of return for sites with light residual hardwoods when expected, worst, and best treatment outcomes result from various treatment methods, by site index and rotation length

| Treatment method | Treatment outcome and site index[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Expected | | | Worst | | | Best | | |
| | 50 | 60 | 70 | 50 | 60 | 70 | 50 | 60 | 70 |
| | (percent) | | | | | | | | |
| | 20-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | 0.9 | 6.3 | 10.4 | --[2] | 5.2 | 9.5 | 1.9 | 7.2 | 11.3 |
| Moderate | 1.2 | 6.5 | 10.5 | 0.4 | 5.8 | 9.8 | 1.6 | 6.9 | 10.8 |
| Heavy | 1.7 | 6.9 | 10.8 | 1.0 | 6.3 | 10.3 | 1.9 | 7.1 | 11.0 |
| Chemical | 0.9 | 6.2 | 10.1 | -- | 5.0 | 9.1 | 1.6 | 6.8 | 10.6 |
| | 25-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | 4.9 | 8.7 | 11.7 | 4.2 | 8.0 | 11.0 | 5.6 | 9.4 | 12.2 |
| Moderate | 5.0 | 8.7 | 11.5 | 4.6 | 8.3 | 11.2 | 5.3 | 9.0 | 11.7 |
| Heavy | 5.3 | 9.0 | 11.7 | 4.9 | 8.6 | 11.4 | 5.5 | 9.1 | 11.8 |
| Chemical | 4.8 | 8.5 | 11.2 | 4.0 | 7.7 | 10.6 | 5.2 | 8.8 | 11.5 |
| | 30-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | 6.3 | 9.1 | 11.3 | 5.7 | 8.6 | 10.9 | 6.7 | 9.6 | 11.7 |
| Moderate | 6.2 | 9.0 | 11.1 | 5.9 | 8.7 | 10.9 | 6.5 | 9.2 | 11.3 |
| Heavy | 6.5 | 9.1 | 11.2 | 6.1 | 8.9 | 11.0 | 6.6 | 9.2 | 11.2 |
| Chemical | 6.0 | 8.7 | 10.8 | 5.5 | 8.3 | 10.5 | 6.3 | 9.0 | 11.0 |

[1]Given base age of 25 years.

[2]Indicates negative IRR.

amount of information upon which the analysis was based. The second reason concerns the built-in limitations that were imposed on the study.

Regarding the informational deficiencies, the principal problem was the scarcity of data on probable stand growth responses to chemical site preparation treatments. Though the literature contains numerous reports of chemical pine release studies, only a few investigations involving the use of chemicals for site preparation purposes have been published, and most of those are less than 5 years old. Several researchers considered to be among the most knowledgeable about chemical site preparation in the South were contacted in an effort to supplement the extremely limited amount of reported data, but few were willing to provide judgemental estimates of the stand growth responses that were needed for the study. This lack of either solid measurement data or informed judgements explains why IRR's were calculated not only for the "expected" but also for the "best" and "worst" treatment outcomes. These calculations made it possible to define the range of possible results and provided insights into the reliability of the findings for the "expected" treatment outcomes.

Regarding the limitations that were imposed on the study, two of them are probably of sufficient importance to be stressed. The first restriction was that only one herbicide -- hexazinone -- and only one application method -- aerial spraying by helicopter -- were considered. Although several chemicals are often applied during the course of an operation to achieve maximum effectiveness,

Table 6. -- Rates of return for sites with moderate residual hardwoods when expected, worst, and best treatment outcomes result from various treat ment methods, by site index and rotation length

| Treatment method | Treatment outcome and site index[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Expected | | | Worst | | | Best | | |
| | 50 | 60 | 70 | 50 | 60 | 70 | 50 | 60 | 70 |
| | (percent) | | | | | | | | |
| | 20-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | --[2] | 1.4 | 5.6 | -- | -- | 1.9 | -- | 4.3 | 8.5 |
| Moderate | -- | 3.3 | 7.4 | -- | 1.0 | 5.3 | -- | 4.8 | 8.7 |
| Heavy | -- | 4.0 | 7.9 | -- | 2.3 | 6.3 | -- | 4.9 | 8.6 |
| Chemical | -- | 4.4 | 8.4 | -- | 0.5 | 4.9 | 0.9 | 6.1 | 10.0 |
| | 25-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | 1.3 | 5.2 | 8.4 | -- | 2.6 | 5.7 | 3.5 | 7.3 | 10.2 |
| Moderate | 2.7 | 6.4 | 9.3 | 0.9 | 4.9 | 8.0 | 3.8 | 7.4 | 10.2 |
| Heavy | 3.2 | 6.8 | 9.5 | 1.9 | 5.6 | 8.5 | 3.7 | 7.3 | 9.9 |
| Chemical | 3.5 | 7.2 | 10.1 | 0.3 | 4.6 | 7.7 | 4.7 | 8.3 | 11.0 |
| | 30-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | 3.6 | 6.5 | 8.9 | 1.5 | 4.5 | 6.9 | 5.1 | 8.0 | 10.3 |
| Moderate | 4.5 | 7.3 | 9.5 | 3.3 | 6.2 | 8.5 | 5.3 | 8.0 | 10.1 |
| Heavy | 4.7 | 7.4 | 9.5 | 3.8 | 6.6 | 8.8 | 5.1 | 7.7 | 9.7 |
| Chemical | 5.1 | 7.9 | 10.0 | 3.1 | 6.0 | 8.4 | 6.0 | 8.6 | 10.6 |

[1]Given base age of 25 years.

[2]Indicates negative IRR.

such measures were not included in the analysis because of their prescriptive nature and the lack of adequate response information. Alternative delivery systems were not evaluated to keep the number of required financial calculations within reasonable bounds. The second restriction was that only unthinned stands grown over rotations of 20, 25, or 30 years were considered. Though prudent forest managers will normally thin stands to maintain any growth gains achieved through site preparation, this additional practice was not included in the analysis for fear of confounding the site preparation and thinning responses.

Despite its shortcomings, the study should prove helpful to forest managers facing site preparation decisions. The basic analytical approach is sound, even though some of the input data may be subject to challenge. This being the case, the evaluations can be redone using whatever input values are deemed most appropriate. Over time, as the statistically designed field studies now in place begin to provide additional information on how stands respond to site preparation by all means, it will be possible to make more reliable comparisons between chemical and mechanical treatments.

Table 7. -- Rates of return for sites with heavy residual hardwoods when expected, worst, and best treatment outcomes result from various treatment methods, by site index and rotation length

| Treatment method | Treatment outcome and site index[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Expected | | | Worst | | | Best | | |
| | 50 | 60 | 70 | 50 | 60 | 70 | 50 | 60 | 70 |
| | (percent) | | | | | | | | |
| | 20-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | --[2] | -- | 2.5 | -- | -- | -- | -- | 2.4 | 6.5 |
| Moderate | -- | 1.0 | 5.2 | -- | -- | 2.5 | -- | 3.6 | 7.5 |
| Heavy | -- | 2.1 | 6.0 | -- | -- | 3.8 | -- | 3.2 | 6.9 |
| Chemical | -- | 3.3 | 7.4 | -- | -- | 2.3 | 0.1 | 5.6 | 9.5 |
| | 25-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | -- | 3.0 | 6.0 | -- | -- | 2.0 | 2.0 | 5.8 | 8.8 |
| Moderate | 1.0 | 4.8 | 7.8 | -- | 2.9 | 5.9 | 2.8 | 6.5 | 9.3 |
| Heavy | 1.7 | 5.3 | 8.0 | -- | 3.7 | 6.6 | 2.4 | 6.0 | 8.6 |
| Chemical | 2.7 | 6.4 | 9.3 | -- | 2.8 | 5.8 | 4.4 | 8.0 | 10.7 |
| | 30-YEAR ROTATION | | | | | | | | |
| Mechanical | | | | | | | | | |
| Light | 1.8 | 4.8 | 7.2 | -- | 1.7 | 4.1 | 4.0 | 6.9 | 9.2 |
| Moderate | 3.2 | 6.0 | 8.3 | 1.7 | 4.6 | 6.9 | 4.5 | 7.2 | 9.3 |
| Heavy | 3.6 | 6.2 | 8.3 | 2.3 | 5.1 | 7.3 | 4.1 | 6.7 | 8.7 |
| Chemical | 4.5 | 7.3 | 9.5 | 1.6 | 4.6 | 7.0 | 5.7 | 8.3 | 10.4 |

[1]Given base age of 25 years.

[2]Indicates negative IRR.

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# GROWTH AND ECONOMIC COMPARISONS OF SELECTED NATURALLY AND ARTIFICALLY REGENERATED STANDS[1]

Michael T. Mengak, David H. Van Lear,
Stephen K. Nodine, and David C. Guynn, Jr.[2]

ABSTRACT.--Growth and financial rates of return were compared for plantations and naturally regenerated stands of loblolly pine (Pinus taeda L.). Analyses of spatial pattern indicated that trees in natural stands were distributed in dense, random clumps, while plantations had less dense, more uniform patterns. Computer simulations predicted that 30-year yields for natural stands would be 21.2 cords/acre giving an 11.9% internal rate of return. Limiting seedbed preparation to two burns with natural stands yielded a 16.4% internal rate of return. Projected 30-year yields for plantations were 28.1 cords/acre, with an 11.0% internal rate of return. Since establishment costs of plantations were nearly double those of natural stands, these results suggest that small landowners could use natural regeneration to lower their initial investment and obtain a higher rate of return.

## INTRODUCTION

Escalating costs have prevented many non-industrial landowners from regenerating harvested land back to pine. Hardwood invasion of pine sites is increasing. Sheffield (1979) found that over 42 percent of all pine types harvested in South Carolina between 1968-1978 have reverted to oak-pine or hardwood types.

Natural regeneration of loblolly pine (Pinus taeda L.) has been proposed as an alternative to plantation establishment for small, nonindustrial landowners because it is less costly, more aesthetically pleasing, and can yield higher financial returns (Williston 1978, Van Lear et al. 1983). Much is known about the silvicultural methods used to naturally regenerate loblolly pine in both the Coastal Plain and the Piedmont (Brender 1973, Lotti 1961, Langdon 1981, Van Lear 1982). However, relatively few studies have compared growth and economic returns of natural stands to that of plantations. Nor have economic evaluations of performance of natural and planted stands been frequently addressed.

This paper reports on spatial patterns, growth, and projected yields of loblolly pine in plantations and natural stands in the Piedmont of South Carolina, and compares rates of return on initial investments in regeneration.

## METHODS

### Study Areas

Twenty-five stands were randomly located on medium quality sites in the Piedmont Plateau Province of western South Carolina in Abbeville, Edgefield, Greenwood, McCormick, and Saluda counties. Stands ranged in age from 2 to 22 years. Stands were not thinned and, except for site preparation, had no recent history of fire. Soils were Ultisols, mainly Udults. Average annual temperature in the study counties is 62°F and yearly precipitation averages 59 inches (NOAA 1985).

Natural regeneration on ten sites was by the seed-tree method. Previous stand types were 40- to 50-year-old old-field loblolly and shortleaf pine (P. echinata). Site preparation consisted of chopping residual stems and logging debris followed by broadcast burning. Regeneration was rapid following this relatively intense site preparation treatment. Because there was no lag period in regeneration and because no cost or incomes associated with harvest of seed trees were available, economic analyses on natural stands were conducted as if regeneration were by clearcutting with seed in place.

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Fifteen plantations were also selected. Site preparation was by chopping followed by broadcast burning. Plantations were planted with 1-0 loblolly pine seedlings on a 6 x 10 ft spacing to yield an initial density of 726 trees/ac.

### Data Collection

Twenty-five 0.01 ac plots per study site were randomly located and sampled for pine tree density, height and diameter. Height and DBH of the dominant pine in each 0.01 ac plot was measured (dominance was defined as the tallest tree in the plot). Height and diameter of all pines was averaged by stand age. Average height and diameter was plotted against age for natural and planted stands. Least squares analysis was used to fit a straight line to the data. Differences in slope of the regression lines was used to compare height and diameter growth rates between natural and planted stands. Basal area was determined on the seven oldest stands by measuring DBH on all trees (pine and non-pine) within randomly located 0.05 ac circular plots. Each of these seven stands was between 13 and 22 years old.

Density of pines was measured by counting the number of living pines in each 0.01 ac plot. Two measures of tree spatial pattern were computed using the mean and variance of trees per 0.01 ac plot. First, the "coefficient of dispersion" (D) (Grieg-Smith 1964:65) was computed as

$$D = (\text{Variance/Mean Density}).$$

A value of D = 1 indicates a random distribution, values less than 1 indicate a uniform pattern, while values greater than 1 indicate a clumped arrangement (Greig-Smith 1964:66). The second measure of spatial pattern, Lloyd's "index of crowding", (m*) (Pielou 1977:131) was computed as a measure of the mean number of neighbors around individual stems in each sample plot. Numerically, crowding is the sum of mean density and the index of clumping. Crowding is experienced by each individual in the population and depends on density (Pielou 1977:131).

Volume projections and economic forecasts were made using the YIELD (version 1.4) software package (Hepp 1985) with the assumptions given in Table 1. Cost estimates are from Moak et al. (1983) and are the most recent regionwide figures available.

Table 1. Assumptions used in economic comparison of natural regeneration and planting of loblolly pine.

| Factor | Assumption |
|---|---|
| Site | Piedmont site - $SI_{50}$ = 67 for natural stands and $SI_{25}$ = 56 for plantations |
| Rotation | 30 years, with no thinnings |
| Wood prices | \$14/cd and 4% inflation<br>\$140/MBF and 5% inflation |
| Site preparation costs | \$67.86/ac single chop<br>\$7.11/ac burn after chopping<br>\$53.72/ac planting cost<br>\$12.50/ac seedling cost |
| Ad valorem tax | \$1.00/ac/year |
| Marginal federal tax bracket | 35% |
| Capital gains proportion | 40% |
| Discount rate (before taxes) | 8% |
| Harvest expense | 10% of harvest value |
| Reforestation tax credit | 10% (up to limit of \$10,000 annual investment) |
| Amortization period for reforestation expenses | 84 months |

## RESULTS AND DISCUSSION

### Current Stand Conditions

Distribution of trees was considerably different between natural stands and plantations (Fig. 1). In natural stands, the range of density within sample plots was wide with 13 percent of the 0.01 ac plots having 0 or 1 trees and 22 percent of the plots having 20 trees or more. A few plots had as many as 70-80 seedlings. The index of clumping was high (21.9) and indicated a significant departure from a random distribution ($t = 243.4$, d.f. = 247, $P < 0.001$).

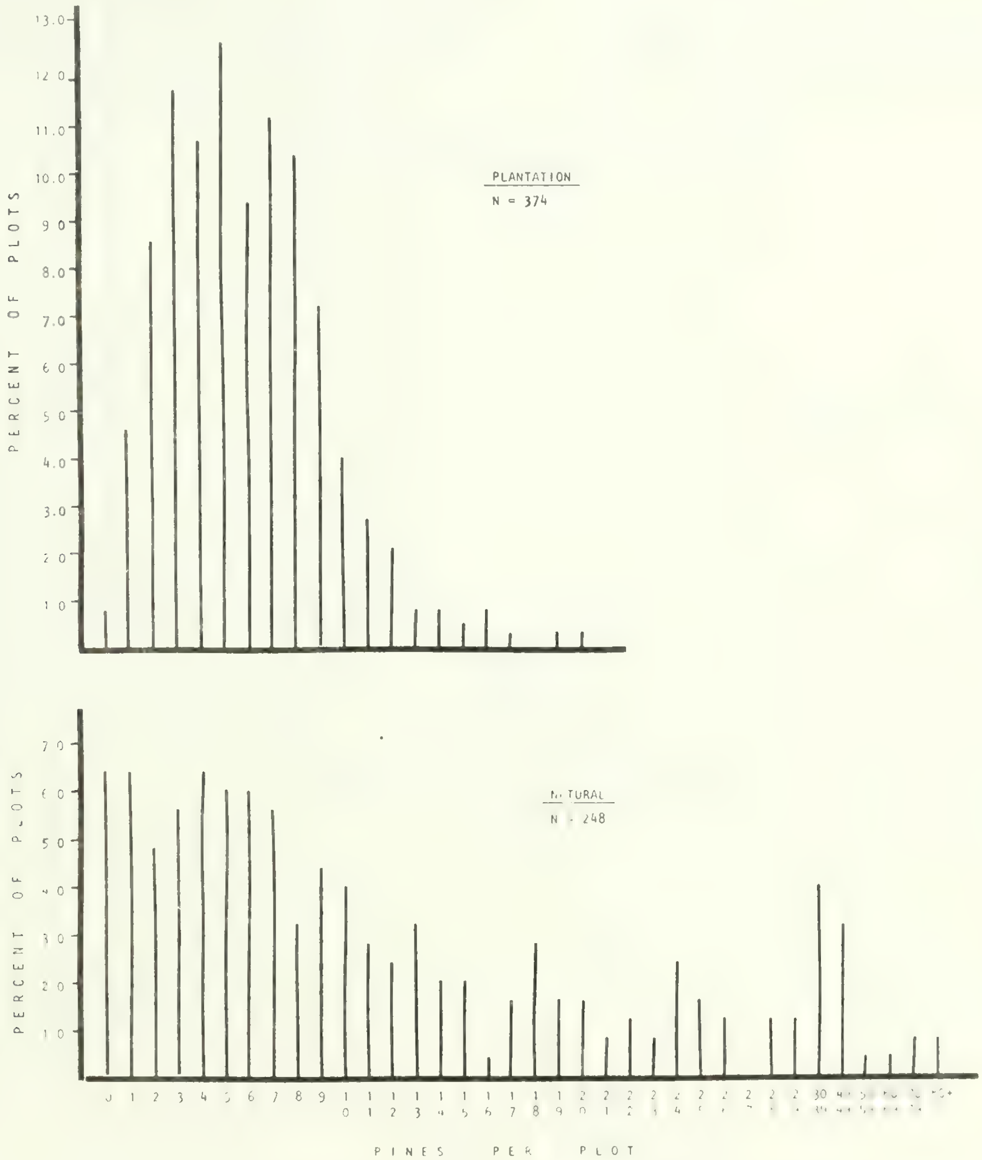


Figure 1. Frequency distribution of number of loblolly seedlings on 0.01 ac plots on natural stands and plantations of loblolly pine in five South Carolina Piedmont counties.

The index of crowding was 34.2. Taken together, values of clumping and crowding indicate that these natural stands consisted of dense, randomly distributed clumps of trees. Askew (1983) found similar results for natural loblolly stands aged 4 to 29 years in the South Carolina Coastal Plain.

In plantations, density was less variable with only 5 percent of the plots having 1 tree or less. Also, no plots had more than 20 trees. The index of clumping was low (1.9) indicating a significant departure from a random distribution ($t = 25.3$, d.f. = 373, $P < 0.001$). The index of crowding was 6.9. Plantations begin as an ordered arrangement of seedlings, but random deaths in the stand contribute to the formation of occassional clumps of pines. These clumps are less dense (i.e., less crowded) than in natural stands.

A linear relationship adequately describes height growth of loblolly pine in both natural and planted stands during the first 22 years (Fig. 2). Mean height growth rate of pines in planted stands was 2.5 ft/yr (SE = 0.2 ft/yr),

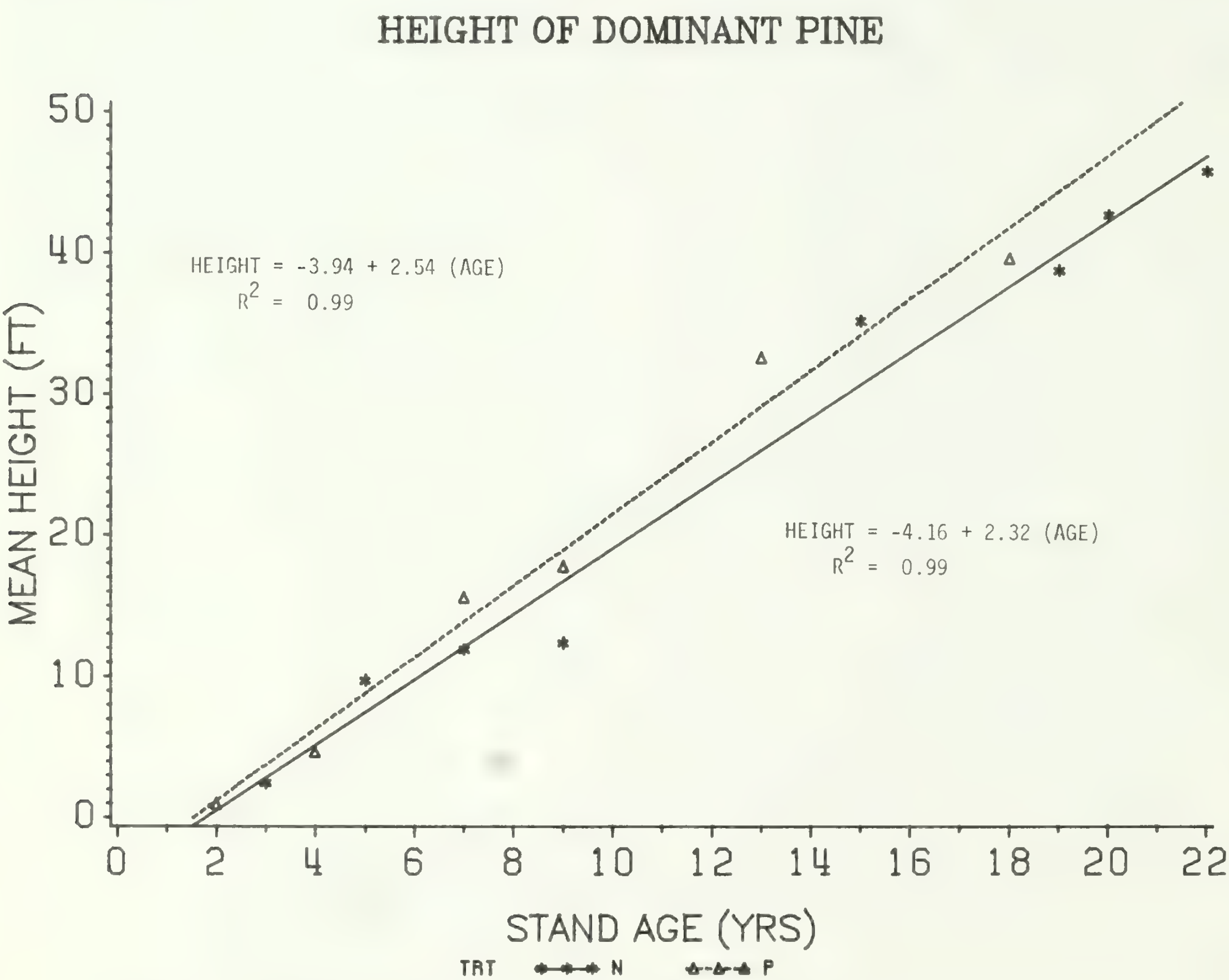


Figure 2. Average height of dominant pines as a function of age on natural and planted loblolly pine stands in five South Carolina Piedmont counties.

while in natural stands it was 2.3 ft/yr (SE = 0.14 ft/yr). Estimates of height growth rate were not significantly different (F = 0.84, d.f. = 1,12). Average DBH of dominant pines was also plotted against age (Fig. 3). Mean diameter growth rate of pines was 0.42 in/yr (SE = 0.06 in/yr) and 0.34 in/yr (SE = 0.04 in/yr) for plantations and natural stands, respectively. Estimates of diameter growth rates were not significantly different (F = 1.14, d.f. = 1,9). There is a trend toward slower growth on natural stands that may be related to spatial patterns; however, this trend was not statistically significant.

Since basal area and DBH parameters are meaningless on young stands, basal area merchantable stems (≥ 4.0 in DBH) were pine and 14.3 percent were non-pine. Total basal area was 134.3 $ft^2$/ac with pine comprising 75.2 percent of the total. Total basal area in merchantable stems was 100.1 $ft^2$/ac, of which 83.6 percent was pine. In plantations, 98.8 percent of merchantable trees were pine. Total basal area was 97.1 $ft^2$/ac, of which 93.8 percent was pine. Total merchantable basal area was 80.4 $ft^2$/ac, of which 99 percent was pine.

## Projections and Economic Analysis

Internal rates of return for natural regeneration and plantations, based on assumptions listed in Table 1, were calculated after growth and yield had been projected to 30 years. We had

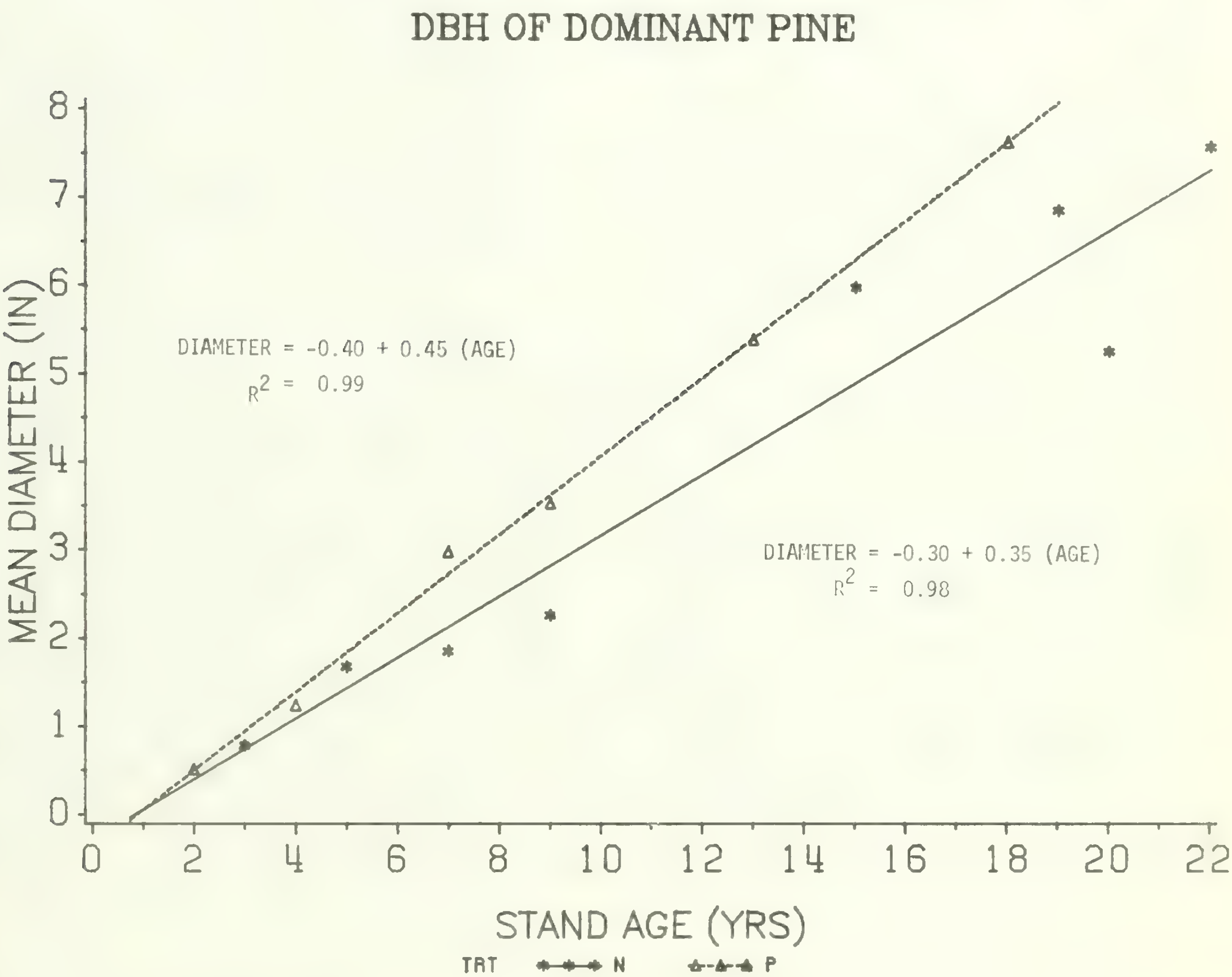


Figure 3. Average diameter of dominant pines as a function of age on naturally regenerated and planted loblolly pine stands in five South Carolina Piedmont counties.

intended to model all 7 of the oldest stands; however, one plantation was eliminated because volunteer seeding produced an atypically high density of 900 trees/ac at age 13. Therefore, the more realistic density of 425 trees/ac, which characterized the two other plantations, was used in the growth simulation program. Also, two natural stands were eliminated because the YIELD software requires that natural stands be at least 20 years old. Thus, our simulations are based on two natural and two planted stands. Stand parameters of these stands are shown in Table 2.

Projected yields at age 30 averaged 21.2 cords/ac on the two natural stands and 28.1 cords/ac on 2 plantations. These projections were lower than those from other simulation programs (Burk and Burkhart 1984, Amateis et al. 1984). YIELD was selected because, unlike other programs, it provides an economic comparison of stands in addition to a projection of volume.

Simulations indicated that plantations would out-produce natural stands by nearly 7.0 cds/ac over a 30-year rotation. However, since establishment costs for plantations were nearly double those of natural regeneration, the internal rate of return would be similar for both methods of regeneration (Table 3). Van Lear et al. (1983) suggested that clearcutting with seed in place would yield a higher rate of return than artificial regeneration. We made a second simulation of natural stands using two seed bed preparation burns (at a cost of $7.50/ac), rather than chop and burn for site preparation, and found the IRR to be 16.4 percent, about 5.4 percent greater than that for plantations.

## SUMMARY AND CONCLUSIONS

Growth and yield of natural stands can be similar to that of plantations established by the same site preparation treatments. Distribution of seedlings for natural stands is different from that of plantations. Natural stands exhibit more clumping and have higher indices of crowding. Natural regeneration, when used under appropriate conditions, can yield financial returns equal to or exceeding returns from plantations. Growth of natural stands may be improved if economical ways to precommercially thin dense clumps of seedlings can be devised. If not properly planned and coordinated, the risk of natural regeneration failure is greatly increased--a possibility we did not include in our analyses. However, the methodology of establishing natural regeneration is well known, and successful regeneration is consistently possible if proper techniques are used.

Table 2. Average current conditions on two natural regeneration stands and two plantations of loblolly pine in the western South Carolina Piedmont.

| Stand Parameter[a] | Natural | | Plantation | |
|---|---|---|---|---|
| | N1 | N2 | P1 | P2 |
| Age (yrs) | 20 | 22 | 13 | 18 |
| Site index (ft)[b] | 67 | 67 | 56 | 50 |
| Density (trees/ac) | 309 | 520 | 425 | 425 |
| DBH (in) | 5.3 | 4.7 | 4.5 | 6.7 |
| Height (ft) | 37.3 | 36.0 | 27.7 | 34.3 |
| Pine basal area ($ft^2$/ac) | 67.1 | 101.5 | 54.7 | 113.7 |

[a]Loblolly pine only

[b]Site Index: age 50 for natural stands, age 25 for plantations

Table 3. Projected (to age 30) woodflow and financial analysis for two natural stands and two plantations of loblolly pine in the western South Carolina Piedmont.

| Stand Parameter[a] | Natural | | Plantation | |
|---|---|---|---|---|
| | N1 | N2 | P1 | P2 |
| Density (trees/ac) | 309 | 484 | 312 | 333 |
| Height (ft) | 56 | 56 | 58 | 54 |
| Pine basal area ($ft^2$/ac) | 98 | 124 | 103 | 98 |
| Sawtimber (MBF/ac) | 2.5 | 1.8 | 3.2 | 3.2 |
| Pulpwood (cds/ac) | 13.7 | 19.0 | 21.4 | 22.7 |
| Total cords (per ac) | 19.3 | 23.1 | 27.4 | 28.7 |
| Regeneration cost ($) | 75 | 75 | 140 | 140 |
| Internal rate-of-return (%) | 12.0 | 11.7 | 11.0 | 11.1 |

[a]Loblolly pine only

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# FINANCIAL ANALYSIS OF ARTIFICIAL PINE REGENERATION AND NATURAL REGENERATION USING IMPROVEMENT CUTS[1]

Stephen K. Nodine and Arthur T. Shearin[2]

ABSTRACT.--In 1953 a 2-acre portion of a shortleaf pine-mixed hardwood stand was clear cut. The following year loblolly pine was planted and residual hardwoods were killed. The remaining acres of the original stand received an improvement cut in 1953, with no artificial regeneration. Part of that area was also eventually converted to pine by 1961. None of the three resulting stands received any treatment following that time. After 31 years of growth the loblolly pine stand produced 12.5 MBF of sawtimber and 30 cords of pulpwood per acre, while the adjacent pine-hardwood stand produced 9.7 MBF of sawtimber and 4.4 cords of pulpwood per acre. After-tax annual equivalent values (AEV) for the pine and mixed pine-hardwood stands were \$16.21 and \$6.19, respectively. Even higher returns of up to \$24.20 were projected under more intensive management schedules. The area which was eventually also converted to pines was projected to earn an AEV of \$22.49.

## INTRODUCTION

Nonindustrial private forest (NIPF) landowners currently control 74% of the 204 million acres of commercial forest land in the South. They have historically tended to be reluctant to invest heavily in their forest land. As a result, one approach that many take with regard to mixed stands is to thin them with what they may call "improvement cuts," taking some of the trees and leaving the rest to provide for regeneration and continued growth. The attitude of "my Daddy and my Daddy's daddy cut over this stand many times and neither one of them ever replanted any trees" prevents many owners from being willing to invest their money in reforestation activities. Unfortunately, this approach often amounts to little more than high-grading the stand.

Much has been written on the management of pine stands and the economic returns that are possible from such investments. Much less has been written, however, about the returns to be expected from managing mixed pine-hardwood stands, especially when they are under the extensive type of management that is common among many NIPF owners. Many NIPF owners tend to resist the idea of converting a mixed species stand to a pine monoculture. This is partly due to the relatively high cost of such conversion, and partly to aesthetic concerns. By making the decision to continue thinning a mixed stand rather than converting it to a pine stand, owners may decrease the value of the stand and reduce the returns that they can earn from light to moderate investments in reforestation.

This paper investigates a case history of a stand, part of which was converted from mixed pine and hardwoods to pines, and part of which was thinned in an "improvement cut." Actual stand growth is reported, as well as simulated growth under alternative management schedules. An economic analysis compares the profitability of each alternative and evaluates their relative merits. The results are not limited to NIPF applications, however, but have relevance to all forest land.

## THE STUDY AREA

The study area is a 37-acre stand located in the northern Piedmont region of South Carolina. The stand is a part of Clemson University's forest which is managed for educational and experimental purposes, as well as for its commercial value. The site has a loblolly pine site index of 105 at age 50. In 1953 this area contained a mature (70-80 years old) upland stand composed of shortleaf pine and mixed hardwoods. As a demonstration of the emerging practice of chemical hardwood control, two acres of the stand were harvested with only commercial trees being removed. In 1954 this area was planted with loblolly pine, and in 1955 the residual hardwood stems were killed. Through these steps this stand was successfully converted from mixed pine and hardwoods to loblolly pine at a cost of approximately 20% of the value of the timber harvested.

The remaining 35 acres of this stand were also harvested in 1953 with what was intended to be an "improvement cut." Nearly all merchantable hardwood stems were cut along with a partial harvest of the shortleaf pine trees. At the time, there was no market in the area for hardwood pulpwood; but it was anticipated that the residual hardwood stems would continue with their growth into merchantable size classes, and that the remaining shortleaf pines would provide some natural regeneration as well as continued growth.

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[1] Paper presented at the 4th Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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As an indication of the success of this improvement cut, most of the stand was eventually converted to loblolly pine when it was recognized that the residual stand would not continue to grow at a profitable rate. A hardwood pulpwood market developed in the area in 1959, so the remaining merchantable hardwoods were cut and the rest girdled, and the shortleaf pines were cut to a seed tree stocking level. Loblolly pine was planted in a few areas which contained no seed trees. In 1960 loblolly pine seeds were spread by hand to try to improve regeneration. By 1961 regeneration was still less than 200 pines per acre, leading to the planting of more pine seedlings. In 1964 competition from young hardwoods had become a problem for the pine regeneration, so the hardwoods were chemically controlled with 2,4,5-T. Two acres of this stand were not converted, however, to provide a basis for comparing the ultimate results of stand conversion versus improvement cutting. This left three distinct stands with different treatments for comparison.

Since 1964 there have been no management activities on any of the stands. Periodic visits to the first converted stand recorded a very normal growth process. By age 12 the stand had a basal area of 40 sq ft/acre, and by age 21 it had grown to 140 sq ft/acre. A note in the management record at that time recommended "Thin if research allows it."

The two 31-year-old stands were measured in 1985 to determine the results of these two regeneration methods. At that time, the following conditions existed in the two stands:

| | Converted | Natural |
|---|---|---|
| Sawtimber (MBF/acre Int'l ½" rule) | | |
| Pine | 12.5 | 3.8 |
| Hardwood | 0.0 | 5.9 |
| Pulpwood (cords/acre) | | |
| Pine | 30.6 | 1.0 |
| Hardwood | 0.0 | 1.4 |
| Timber value ($/acre) | $1,552 | $582 |

## ECONOMIC ANALYSIS

As indicated earlier, the intent of the comparison between these stand treatments was to evaluate the trade-offs between them. Conversion to a pine plantation gains faster tree growth, higher total volumes, and better stand composition. These benefits are only possible, however, when a significant amount of money is invested and held until trees become merchantable. A primary goal of natural stand management - in this case through an improvement cut - is to reduce the required investment while maintaining a viable stand. Comparisons can be made of the results of these two methods through a simple economic analysis which can account for all of the expenses incurred and incomes received, and the length of time between the initial investment and eventual incomes.

In making an economic analysis one has to select an appropriate economic criterion upon which alternatives will be judged. The most common criteria which are used are Internal Rate of Return (IRR), Present Net Worth (PNW), and Annual Equivalent Value (AEV). Each criterion has its own set of assumptions, advantages, and disadvantages (Foster 1984). In this example, IRR cannot be used because the improvement cut example has no initial investment on which a rate of return can be computed. Since the initial analysis was extended to investment periods of different lengths Annual Equivalent Values must be used for the comparisons.

Simply stated, AEV can be considered equivalent to the annual profit realized by an investment. Since forest stands do not normally return an annual income, one might think of this as an annuity which accumulates value each year but only pays out at a later date. Two assumptions are important to the use of AEV. First, the assumption must be made that timber management is perpetual - that is as one rotation is ended another begins. And second, a discount rate that is appropriate must be selected. This discount rate can be considered to be the cost of money to the woodland owner, or the next-best alternative rate of return that he could earn on his money. Though AEV is sensitive to the discount rate selected, and though it is often hard to get a consensus as to the appropriate rate to use, this analysis uses a representative landowner's discount rate, since the comparison being made is of the relative merits of two alternative management schemes, both of which face the same discount rate.

Several items of information and assumptions necessary to the financial analysis are summarized in Table 1. Since these stands were managed during the time that a capital gains tax differential was in effect and a reforestation tax credit was not, it was assumed that the tax breaks in effect at that time would have been claimed.

When a comparison of the values of the two 31-year-old stands is made, an extreme difference in their profitability becomes apparent. The stand that received an improvement cut had an AEV of $6.19, while the converted plantation had a value of $16.21, nearly 2.5 times higher (Table 2). This might have been anticipated after seeing the volumes of timber that were present in each stand.

Why did the natural stand compare so poorly? It appears that though the intent of the improvement cut was good and the logic sound, the actual implementation of the cut was faulty. The result of a well-executed improvement cut should be a stand of trees which can continue to increase in value at a reasonable rate, move into merchantable size classes, and/or provide for successful regeneration of the stand in the future (Smith 1962). In this case, however, most trees that were left were overmature or poorly-formed; and there were few if any young trees which could grow into merchantable sizes. Subsequent natural regeneration in the stand has been minimal, leaving a stand of slow-growing, overmature or unmerchantable trees. Though the intent of the cutting was to improve the future prospects of the stand, the effect was not unlike that of highgrading.

Table 1.--Assumptions Made and Data Used in the Financial Analysis.

| | |
|---|---|
| Federal income tax rate | 30 percent |
| Before-tax discount rate | 6 percent |
| Capital gains tax exclusion | 60 percent |
| Stumpage prices (1985) | |
| Sawtimber | |
| Pine (Scribner rule) | $110/MBF |
| Hardwood (Doyle rule) | $60/MBF |
| Pulpwood | |
| Pine | $12/cord |
| Hardwood | $4/cord |
| Expenses for pine conversion | |
| Site preparation and planting (1954) | $20/acre |
| Hardwood control (1955) | $10/acre |
| Expenses for delayed conversion to pine | |
| Hardwood control (1959) | $3/acre |
| Planting selected areas (1959) | $7/acre |
| Direct seeding loblolly pine (1960) | $20/acre |
| Planting loblolly pine seedlings (1961) | $21/acre |
| Hardwood control (1964) | $9/acre |
| Expenses for all stands | |
| Annual taxes and general management expenses | $1/acre |
| Harvest expense | 8 percent of harvest value |

Table 2. Comparison of Profitability for an "Improvement Cut," a Converted Stand, and a Delayed Conversion.

| Stand Management Schedule | After-tax Annual Equivalent Value |
|---|---|
| | ($/acre/year) |
| Improvement cut with one harvest at age 31 | 6.19 |
| Converted to pine with one harvest at age 31 | 16.21 |
| Simulated pine conversion with one harvest at age 31 | 14.98 |
| Simulated pine conversion with a thinning at age 21 and a clearcut at age 31 | 20.50 |
| Simulated pine conversion with thinnings at ages 20 and 30 and a clearcut at age 35 | 24.20 |
| Delayed conversion with simulated thinnings at ages 20 and 30 and a clearcut at age 35 | 22.49 |

Reflecting back on the management recommendation at age 21 that the converted pine stand be thinned if research permitted it, an investigation was made of the potential profitability of that stand if it had been managed more vigorously. To do that the cut-over site loblolly pine growth and yield simulator from the YIELD computer program (Hepp 1985) was used. The approximate stand condition at its establishment in 1954 had to be specified in order to simulate thinnings at earlier ages. Approximately 1,000 seedlings were planted per acre as was common practice at that time. Based on this growth and yield model, it was projected that the simulated converted stand would have an AEV of $14.98 if left unthinned, compared to the estimated value of $16.21 for the actual stand. Since the speculative management regimes were based on this same model, this simulated value was used for making comparisons.

Next, several management schedules were simulated with intermediate thinnings and a final harvest by clearcut. It was found that all of the feasible management schedules were more profitable than a straight 31-year single harvest rotation. For example, if the stand had been thinned at age 21 and then clearcut at age 31 the AEV would have been $20.50. Carrying this further, thinnings at age 20 and 30 with a clearcut at age 35 yield an AEV of $24.20, representing an increase in profitability of nearly 50 percent. Any number of other thinning schedules with varying intensities could be tested to find the optimal management plan for such a stand, but the point can be made from these examples that active management with periodic thinnings can often be more profitable than single harvest rotations, depending on the assumptions that are made and the objectives of the landowner.

Since 33 acres of the original stand were delayed in their conversion to pine, it was possible to evaluate the cost of the decision to try an improvement cut. The forest managers realized that the improvement cut had not left a desirable stand of timber, and they began to convert the stand in 1959. It took six years to complete the process, due to several factors including poor natural shortleaf pine regenertion, poor survival from direct seeding, and more intense competition from hardwoods. Total costs for completing this delayed conversion were $60 per acre, compared to $30 per acre for the original conversion. Not only were costs higher; but since the stand was not fully stocked until 1961, there is a seven year delay before the same timber can be harvested. Still, it turned out to be better to eventually decide to convert this stand than to continue with the poorer mixed stand. The AEV of $22.49 for this stand under a simulated schedule of two thinnings and a final harvest compares well with our other examples.

## CONCLUSIONS

Many factors can influence the profitability of various management alternatives for mixed timber stands. This example has demonstrated that these atlernatives should be well-considered before they are implemented. A stand should be evaluated especially carefully before applying some type of "improvement cut" to avoid the types of problems encountered here. Of paramount importance is the age of the trees, as this has great bearing on the ability of stands to continue growing at a profitable rate. Obviously it didn't take the forest managers long to realize that the mixed stand that was given this type of cut was not performing well. Unfortunately, by the time that stand was successfully converted to pine seven more years had elapsed, with a great deal more labor and expense involved and a longer wait for a commercial thinning to become possible.

These implications are important to all forest managers, regardless of whether they work with mixed stands such as these or with single species even-aged stands. Decisions on thinning, harvesting, and regenerating a stand should be made with appropriate financial considerations, and with care taken to insure that the end result is that which was intended. It is especially important that these considerations be presented to private landowners who assume that if one stand of trees grew up on their land another stand will somehow also appear from the remnants of the first.

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# Ten Years After Midrotation Fertilization in Slash Pine Plantations: When Does It Pay?[1]

Duane R. Dippon and Mohammad Hassan[2]

Abstract. In 1975 a series of midrotation fertilization test plots were established by the Cooperative Research in Forest Fertilization Program at the University of Florida. Semimature slash pine plantations were fertilized with eight treatments in a 2 by 4 factorial with phosphorous and nitrogen broadcast on plots. Tree height and DBH were measured on each plot in the year of treatment with follow up measurements at 3, 5, 8, and 10 years thereafter. A Weibull diameter distribution model has been developed for predicting stand development as a function of the level of and time since the fertilization treatment. In general, both the rate of volume accumulation and the resulting total volume per acre are increased. Therefore, the present net worth of the stand as well as it's optimal financial rotation length are expanded by the treatment. Optimal fertilization treatments were found to vary by soil type and final product mix.

## INTRODUCTION

Slash pine (Pinus elliottii Engelm. var Engelm) is one of the major softwood species grown in the southern United States. The species occupies 5.3 million acres in Florida (Bechtold and Sheffield, 1981), and a total of 12.8 million acres east of the Mississippi River (Sheffield et al., 1983). Slash pine ranks first in Florida and third in the Southern states in terms of growing-stock volume, and is favored by many forest managers for its fast growth and excellent utility for pulp, lumber, poles, and gum naval stores (Sheffield et al., 1983).

Demand for wood products from forests in the Southeast is projected to double by the year 2030 (Haeussler, 1983). Because of strong competition for land by agriculture and urbanization for land, intensive forest management must be adopted in order to increase forest productivity and meet future demand without undue price dislocations.

Fertilization is considered an important silvicultural tool for increasing site productivity and accelerating stand development (Duzan et al., 1982), The fertilization of forest stands was first started in the early 1960's in the southeast by industrial forestland owners. New plantations located on phosphorus deficient sites were the primary targets for early forest fertilization efforts (Bengtson, 1979). By 1972, fertilization programs had been extended to include established pine plantations for "midrotation" treatments. Since then, the total area undergoing treatment each year has been increasing steadily (Bengtson, 1979).

The primary objective of this paper is to determine if and when midrotation fertilization applications are financially sound investments. The analysis focuses on the biological and financial responses of 11 test sites to eight treatment combinations of nitrogen and phosphorus. The data for this study was obtained from a series of fertilization trials (B200) carried out by the Cooperative research in Forest Fertilization (CRIFF) program at the University of Florida, Gainesville.

## APPROACH

The CRIFF program is a group venture by forest industires in cooperation with the Department of Forestry and the Soil Science Department of the University of Florida. It was organized in 1967 to promote research in forest fertilization and to assist forest managers in making efficient use of forest soil resources for wood production purposes. The B200 series of fertilization trials were established by CRIFF on cutover forest land to quantify the volume response of established slash pine plantations to nitrogen and/or phosphorus applications. The B200 series consist of 11 tests in a 2 by 4 factorial design with eight treatments in a randomized block design of three replications with all combinations of four levels of nitrogen and two levels of phosphorus.

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[1]Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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| No. | Nitrogen | Phosphorus |
|---|---|---|
| | (#lb lac) | |
| 0 | 0 | 0 |
| 1 | 100 | 0 |
| 2 | 200 | 0 |
| 3 | 300 | 0 |
| 4 | 400 | 0 |
| 5 | 0 | 100 |
| 6 | 100 | 100 |
| 7 | 200 | 100 |
| 8 | 300 | 100 |
| 9 | 400 | 100 |

Gooding et al. (1978) divided the forest soils in the Southeast into seven groups on the bases of drainage class, depth and nature of their B horizon (Table 1). Fisher and Garbett (1980) declared that within these soil groups, chemical tests of soil or foliar nutrient concentrations may then be used to pinpoint deficient areas more precisely.

SOIL GROUP DEFINITIONS

| SOIL GROUP | MAJOR LAND AREA | DRAINAGE | IMPORTANT FEATURES |
|---|---|---|---|
| A | SAVANNAS | VERY POOR TO POOR | SANDY SURFACE LAYER LESS THAN 20 INCHES DEEP, WITH CLAYEY SOIL BELOW |
| B | SAVANNAS | VERY POOR TO POOR | SANDY SURFACE GREATER THAN 20 INCHES DEEP, WITH CLAYEY SOIL BELOW |
| C | FLATWOODS | POOR | SPODIC HORIZON BELOW THE SURFACE LAYER, CLAYEY SOIL BELOW • THE HARDPAN |
| D | FLATWOODS | POOR TO MODERATE | SPODIC HORIZON BELOW THE SURFACE LAYER, SANDY SOIL BELOW THE SPODIC |
| E | UPLANDS | MODERATE TO WELL | SANDY SURFACE LAYER GREATER THAN 20 INCHES DEEP, WITH CLAYEY SOIL BELOW |
| F | UPLANDS | MODERATE TO WELL | SANDY SURFACE LAYER GREATER THAN 20 INCHES DEEP, WITH CLAYEY SOIL BELOW |
| G | SAND HILLS | EXCESSIVE | SANDY SURFACE LAYER AT LEAST 60 INCHES DEEP |

[1]DRAINAGE RATINGS REFER TO THE REMOVAL OF WATER FROM A SOIL. THESE ARE INFLUENCED BY SOIL TEXTURE (SANDS VS. CLAYS) AND POSITION IN THE LANDSCAPE (LEVEL VS. SLOPING LAND). (Table 1)

The wide range in stand density, soil group and treatment ages for the B200 series are listed at the top of the next column.

| TEST | CRIFF TESTS COUNTY & STATE LOCATION | CRIFF SOIL GROUP | AGE AT ESTAB. | SQ. ACRE |
|---|---|---|---|---|
| B150 | Chatham, Ga | B | 15 | 65 |
| B201 | Wayne, Ga | B | 10 | 50 |
| B202 | Wayne, Ga | D | 16 | 68 |
| B209 | Long, Ga | B | 14 | 102 |
| B211 | Nassau, Fl | D | 16 | 77 |
| B219 | Baldwin, Al | E | 15 | 81 |
| B220 | Calhoun, Fl | B | 9 | 20 |
| B221 | Nassau, Fl | D | 15 | 77 |
| B224 | Hamilton, Fl | C | 9 | 41 |
| B227 | Gulf, Fl | A | 13 | 21 |
| B230 | Madison, Fl | G | 13 | 47 |

To quantify the response of slash pine to the different fertilization levels, diameter and height of the trees were measured at the time of treatment and at three, five, eight and ten years thereafter.

Based on the data from the B200 series of mid-rotation fertilization trials, Lynch et al. (1985) developed growth models using the Wiebull diameter distribution technique. Their models estimate the total volume up through and including the eight years after the slash pine plantations were fertilized at mid-rotation. In this analysis, the same procedure was used but updated with the tenth year measurements.

The financial analysis of the growth response, expressed in terms of the Internal Rate of Return (IRR) due to treatment, Net Present Worth (NPW) and Soil Expectation (Se) was performed using the following assumptions:

Regeneration Cost = $146.00/ac
Taxes and Administration = $5.00/ac/yr
Nitrogen = $0.35/lb*
Phosphorus = $0.70/lb*
Uninflated Discount Rate = 4%
Stumpage Market Value = $29.60/cd**

* Material plus application cost
** Merchantable volume inside bark, 2 in. top and Timber-Mart South, North Florida market prices.

These assumptions are included in the analysis which is presented and discussed in the following results section.

The scheduling of applications within the life cycle of the stand is an important aspect that must be evaluated. The scheduling contributes to the total cost of the investment along with the quantity of the volume response and, therefore, the stand's optimal rotation age. Pritchett and Comerford (1983) found that slash pine trees at age 12 to 20 years are more responsive to fertilization than younger trees. They suggested application of nitrogen no later than 5 to 7 years before harvest in order to obtain the maximum benefit from the fertilizer. However, these conclusions are based solely from a biological standpoint, and may not be optimal from an economic viewpoint.

RESULTS AND DISCUSSION

Since the model originally developed by Lynch et al. (1985) predicts future survival, height and Weibull based diameter distribution based on treatment intensity and time since the activity, it should be possible to estimate the optimal fertilization level and timing for the individual tests. By projecting the development of a stand after a midrotation fertilization treatment, volume responses can be quantified for future ages. Although the availability of the diameter distribution of the stand allows detailed analysis of the financial implications of fertilization on multiple products production, this study will simplify the analysis and assume that pulpwood is the only merchantable product.

Figures 1, 2 and 3 display the comparative height, diameter and volumes per acre, respectively, for tests from Soil Groups G, B, D and E (from left-to-right). The subscript (C) represents the unfertilized control while the subscript (F) corresponds to the tests receiving 400 and 100 pounds per acre of N and P, respectively.

The tests demonstrate a great deal of variability to treatments in all respects. The average height growth (Figure 1) of the control plots in test B201 exceeded that of the full treatment plots. Conversely, the fully treated plots heights grew by almost 15 percent over that of the control by 10 years after the treatment for test B211. Whereas the average height growth differences were almost indistinguishable for the plots in test B201, the average tree diameter expanded by nearly 9 percent, the largest difference demonstrated for these four tests (Figure 2). After treatment survival ranged between 79 and 86 percent for the treated trees from the year of the study's initiation to ten years thereafter.

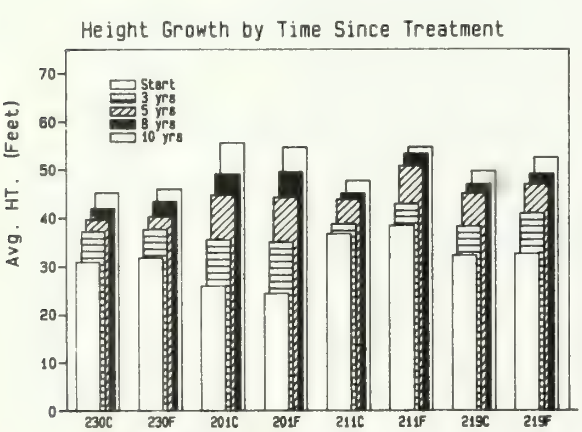


Figure 1. Average tree height by test and time since treatment (control vs. full)

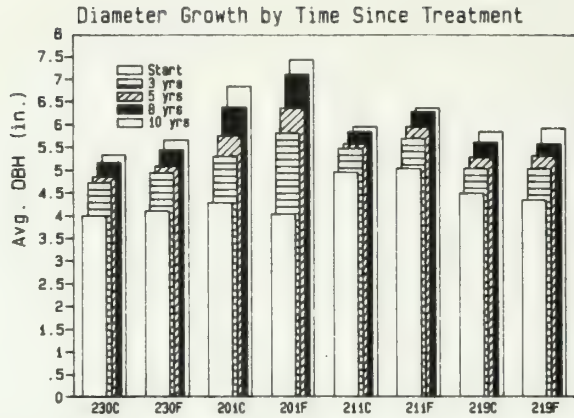


Figure 2. Average tree DBH by test and time since treatment (control vs. full)

After combining survival, height growth, and diameter distribution changes; Figure 3 displays the relative changes between the control and fully treated plots in terms of average volume per acre. Tests B201 and B211 increased their volumes by 16.7 and 20.7 percent, respectively, over that of the control plots after 10 years of growth following the fertilization treatment. The other tests increased their net per acre volumes by approximately 10 percent.

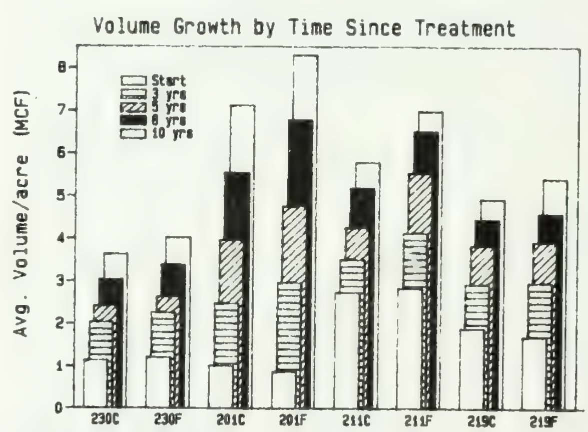


Figure 3. Average volume per acre by test and time since treatment (control vs. full)

Figure 4 demonstrates the maximum volume responses for each of the tests for the range of treatments by ten years after the initial treatment. The most notable implications of these results is that while all of the tests appear to respond favorably to at least some level of nitrogen, the "best" treatment varies by test. In fact, only three tests do best with nitrogen alone (#4-400 lb./ac.) whereas all of the others require 100 pounds of phosphorus along with some positive level of nitrogen. At this juncture, it is difficult to ascertain whether the optimal treatment level varies by CRIFF Soil Group.

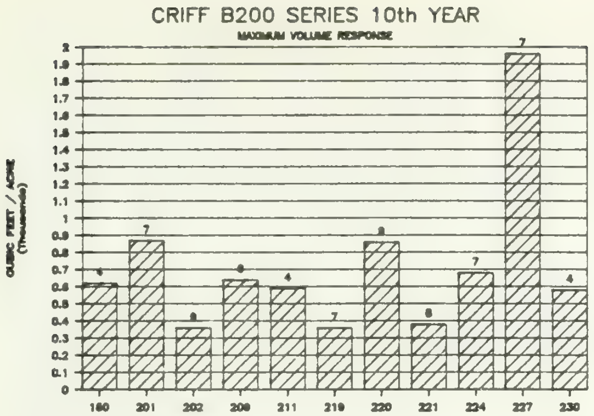


Figure 4. Maximum 10th year cumulative volume response by CRIFF B200 Test

The "optimal" fertilization treatment should at least be based on whether the volume responses are sufficient to repay the costs incurred, and if so, how long the investments should be made before liquidating the stand. This is actually a joint optimization problem with the level of fertilization treatment, or intensity, serving as the initial cost of the investment while the number of growing seasons after the treatment represents the effect of the time value of money on the length of the investment.

Figure 5 displays the diversity of the Internal Rate of Return (IRR)'s possible for a subset of the B200 series of tests for each treatment intensity. The figure demonstrates that the degree of response varies differently among tests for each of the levels of treatment intensity.

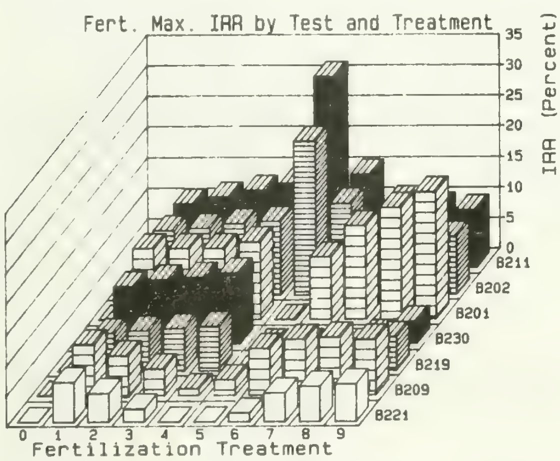


Figure 5. Maximum IRR to midrotation fertilization by test and treatment

But these results only focus on the cost of the treatment versus the value of the treatment response over that of the control. While the figure does convey the most financially responsive treatments by test, the projected growth and development of the stand as an entity is ignored with the IRR procedure. If both the intensity of treatment and length of investment is to be optimized, then the changes in the Present Net Worth (PNW) of the stand can be examined for each test. Figure 6 displays the per acre PNW of the stand over the entire range of fertilization treatments after ten years of growth. While the general trends in the value response due to the fertilization continue from Figure 5 to Figure 6, the latter figure demonstrates that large IRR values do not necessarily translate to significant changes in the stands overall PNW. In other words, whereas the individual treatment may generate a value response of 20 or 30 percent (Tests B202 and B211 with 100 lb./ac. of P), the net value of the entire stand may be only changed by a few percent.

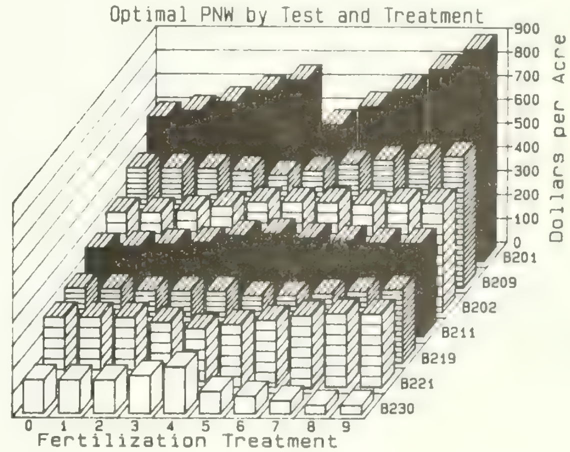


Figure 6. Maximum per acre PNW by test and treatment

The resulting change in total stand value (PNW) helps in defining the optimal fertilization level for the current stand in each test. However, Figure 7 demonstrates that the optimal fertilization intensity may vary if the Soil Expectation (Se) is the decision criteria used for the joint optimization problem instead of the PNW criterion. As Davis and Johnson (1987) explain, the optimal rotation decision should be based on Se rather than PNW since the latter ignores the cost of delaying future cash flows from the land as compared to evaluating the value of the current stand as an entity to itself.

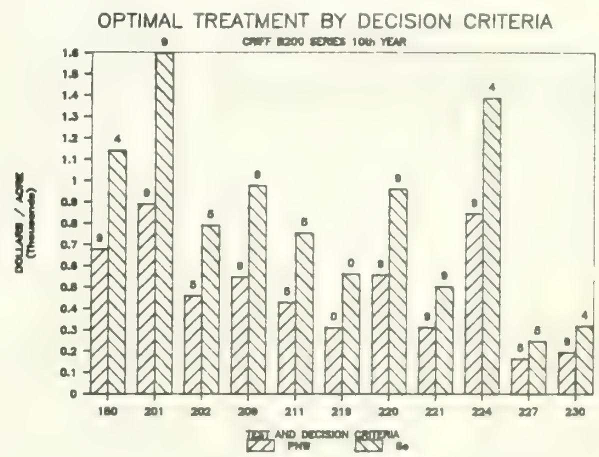


Figure 7. Optimal treatment by CRIFF B200 Test

Although the decision criteria calculate different dollar values, the figure demonstrates that only three tests (B150, B224, and B230) change the optimal treatment intensity for the two decision criteria. In the three cases where a change occurs, the optimal treatment defined by the Se criterion, drops the nitrogen from the optimal PNW treatment, 400 N and 100 P pounds per acre, for the three tests. The optimal treatment intensity for the other tests are unaffected by this change in decision criterion.

While the intensity of treatment may not be very variable to the two decision criteria, Figure 8 displays that the jointly determined rotation length is highly sensitive. In all cases, the Se optimal rotation length is less than or equal to that determined by the PNW criteria. When keying on the Se value decision criterion, the combination of Figures 7 and 8 present the optimal treatment intensities and rotation lengths for each of the B200 series of tests. Referring back to Figure 4, the economically optimal fertilization treatments were not always determined by simply examining the biologically optimal treatments. In addition, the set of economically optimal treatments can be expected to be changed as the cost of materials, application, value of final products or the alternative rate of return assumptions are altered to fit the real world situation of the forest manager.

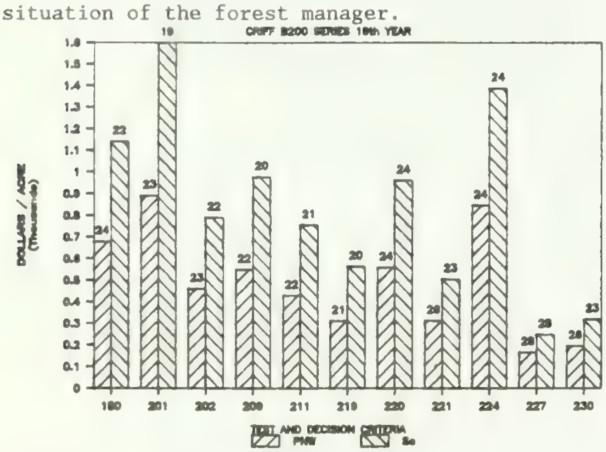


Figure 8. Optimal Rotation by CRIFF B200 Test

DISCUSSION

Returning to the CRIFF Soil Groups, several points can be made. The phosphorus deficient A soils (B227) respond best to 100 pounds/acre of phosphorus. However, the optimal rotation length is really unknown with an alternative rate of return of 4 percent (i=0.04) since the Se value continues to increase up through the fifteenth year of the projection. In reality, such soils would be probably be better served by a phosphorus treatment at the initiation of the stand rather than at some point during midrotation.

The model does not appear to give very good projections when the age of the stand at initialization was less than ten years of age (B220 and B224). The initial feeling by the authors is that the plots are growing at such rapid rates at these younger ages and the time frame for measurements is so brief relative to the stand's development, that the projections of stand value consistently increase at a rate greater than four percent.

For the most part, the B Soil Group tests (B150, B201, B209, and B220) respond best to a treatment of 400 N and 100 P per acre with an investment period ranging between 6 and 9 years. The optimal rotation ages for these tests varies between 19 and 22 years of age.

The only other CRIFF Soil Group which has more than one representative B200 test is that of the D group with B202, B211 and B221. Cooperators have indicated that the last test has suffered unusual mortality levels due to fusiform rust and may therefore not present a good estimate of response to midrotation fertilization. Therefore, if the first two tests are considered alone, 100 pounds of phosphorus per acre alone over a 5 to 6 year investment period appears to be the optimal treatment for the D Soil Group.

The only test for the E soil Group (B219) indicates that midrotation fertilization of any intensity or duration is unprofitable. The control is the optimal treatment with a harvest of the stand by age 20. Conversely, the test from the Soil Group G (B230) indicates that 400 pounds of nitrogen per acre can be successfully invested for 10 years with a resulting optimal rotation age of 23 years of age and a real rate of return of 4 percent.

SUMMARY

The authors realize that the B200 Series of midrotation fertilization treatments represent a very small data set on which to base broad management prescriptions. What is presented is a discussion of the proper methodology for the determination of the joint optimization problem, intensity and investment period. Based on the estimated production relationships and financial assumptions, the calculations indicate that given the economic assumptions made, midrotation fertilization appears profitable for all but one of the tests. In addition, except for the tests which were less than ten years of age at treatment (B220 and B224) and the one test from Soil Group A (B227), the optimal rotation ages for these slash pine sites ranged between 19 and 23 years of age. While the site index values for the sites are unknown, these rotation ages are comparable for optimally defined (Se) rotation lengths for untreated stands based on other slash pine growth and yield models.

Although the analysis approached the problem as a two variable joint optimization problem, in reality it is much more complex. The real question is not just how much fertilizer and then when to harvest the stand, we really also need to know at what age should the treatment be initiated? In addition, we could also include the option of the optimal timing and intensity of thinning operations in the stand. The original study did not provide the level of data necessary to answer the former question. Fortunately, it has been an operational rule of thumb that slash pine stands do not react well to silvicultural treatments once crown closure has occurred.

treatments once crown closure has occurred. Therefore, given the surviving density of the stand, a forester in the field may be able to determine whether fertilization may be attempted. Once the decision has been made, the methodology presented can be used as a guide in determining the optimal treatment and length of investment for the stand.

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# TWENTY-YEAR SLASH PINE SPACING STUDY: WHAT TO OPTIMIZE?[1/]

Doug Bowling[2/]

Abstract.--Measurements at 5, 10, 15, and 20 years are summarized for a slash pine spacing study in Decatur County, Georgia. Four densities (400, 600, 800, and 1000 trees/acre (TPA) planted) were overlaid by a thinning treatment at age 15 on half of the plots. Twenty-year yield is financially analyzed four ways: (1) pulpwood only, (2) merchandising chip & saw, (3) pulpwood adjusted for logging cost, and (4) merchandising with a logging cost variable. Optimum spacing varies with analysis, but unthinned 400 TPA appears superior at age 20.

## INTRODUCTION

One of the first and most important management decisions in a pine rotation is the initial planting density. This decision is commonly a controversial issue, since it involves seeking a financial optimum. Determining that optimum requires forecasting at least 20 years into the future. Market values and specifications (size and wood quality) for those products must be established.

Perhaps most speculative of all, the performance of forest products must be compared to the general economy. This forecast indexes relative appreciation or depreciation of those products. With all this guessing, a single answer to the optimum spacing will not go unchallenged.

This paper presents and discusses a slash pine spacing study that has been measured over the last 20 years. Various approaches to determining the optimum spacing will be considered.

## METHODS

In the spring of 1964, a replicated slash pine spacing study was planted at International Paper Company's Southlands Experiment Forest in Decatur County, Georgia. The site selected was an old-field on an Orangeburg soil. Six replications of this study are presented in this paper. Four spacing treatments are installed within each replication: 400, 600, 800, and 1000 TPA. To ensure accurate spacing, extra seedlings were planted adjacent to the study. After the first growing season, any seedlings that died were replaced using a Council transplanter to maintain soil around the roots.

Following the 15-year measurement half of the plots, three reps, were selectively thinned to a basal area (BA) of 80 ft$^2$/acre across all spacings. A row was removed for access in the 800 and 1000 TPA treatments.

Measurement plots ranged from 35 to 65 trees depending on the spacing used. These plots were measured at age 5, 10, 15, and 20 years. Diameter at breast height (DBH), height, and disease condition were collected for each tree on the plot.

Summaries derived from these measurements are total BA and merchantable volume (MVOL) of the 5-inch class and larger to a 4-inch top. The volume equation used at all times was derived by Schmitt and Bower (1970) for slash pine total inside bark volumes. MVOL was calculated using Max and Burkhart (1976) volume ratio approach. Conversion to cords used a factor of 75 ft$^3$ inside bark/cord.

Pulpwood dimensions include the 5-7 inch DBH classes to a 4-inch top. Chip & saw dimensions include the 8-11 inch DBH classes to a 6-inch top. Fifteen percent of the chip & saw size material was devalued to pulpwood because of disease or defect. At the last measurement very few stems exceeded the 11-inch class. Those few stems were included with the chip & saw class.

Timber values were taken from the Southwide Summary of Timber Mart-South July issue (1986). Pulpwood stumpage was listed at $12/cord, and chip & saw stumpage was listed at $31/cord.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, GA, November 4-6, 1986.

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## GROWTH AND RESPONSE

The stand development at ages 5, 10, and 15 years are presented as an average of six replications in Tables 1, 2, and 3, respectively. Stand conditions immediately following the thinning at age 15 are presented in Table 4 for the thinned plots. Table 5 presents the stand summary at age 20 for both the unthinned and thinned treatments. Each is an average of three replications.

Table 1.--Stand conditions at age 5 by initial spacing treatment.

| Variable | 400 | 600 | 800 | 1000 |
|---|---|---|---|---|
| DBH (in.) | 2.3 | 2.3 | 2.2 | 2.1 |
| Height (ft) | 12 | 12 | 12 | 12 |
| BA ($ft^2$/ac) | 12 | 17 | 22 | 24 |
| TPA | 391 | 576 | 758 | 951 |

By age 5 the stand had not yet begun intra-specific competition. The DBH and height measurements showed no important differences. The BA was nearly a direct function of the number of surviving TPA.

Table 2.--Stand conditions at age 10 by initial spacing treatment.

| Variable | 400 | 600 | 800 | 1000 |
|---|---|---|---|---|
| DBH (in.) | 6.1 | 5.5 | 5.2 | 4.8 |
| Height (ft) | 34 | 33 | 32 | 31 |
| BA ($ft^2$/ac) | 77 | 95 | 112 | 122 |
| TPA | 377 | 564 | 737 | 943 |
| MVOL (cd/ac) | 10 | 10 | 9 | 8 |

By age 10 competition between the surviving pine stems had already caused a strong differentiation in DBH across spacings. The largest DBH's were found at 400 TPA, while the greatest BA was found at 1000 TPA. At age 10, however, the merchantable volume was less for 800 and 1000 TPA than for the lower densities. Nearly half the stems at the higher densities had not yet crossed the merchantable limit into the 5-inch class.

Table 3.--Stand conditions at age 15 prior to thinning by initial spacing treatment.

| Variable | 400 | 600 | 800 | 1000 |
|---|---|---|---|---|
| DBH (in.) | 7.6 | 6.7 | 6.2 | 5.8 |
| Height (ft) | 53 | 51 | 51 | 50 |
| BA ($ft^2$/ac) | 115 | 136 | 150 | 154 |
| TPA | 360 | 540 | 691 | 808 |
| MVOL (cd/ac) | 27 | 28 | 28 | 26 |

By age 15 the effect of initial density on individual stem DBH was even more pronounced. The average DBH of the 400 TPA spacing was nearly 2 inches greater than the 1000 TPA. Essentially there was no difference among merchantable volumes across all spacings. The previously non-merchantable stems of the higher densities had grown into the 5 inch class.

Thinning removal in the 400 TPA treatment was 20-30 percent less than the higher densities, but the cut diameter was 1.0-1.5 inches larger. The compensating effect of these two facts definitely impact the logging cost. An analysis should focus on whether the additional 2-4 cords/acre in the higher densities covered the additional cost of harvesting smaller DBH stems.

The residual stand in the 400 TPA treatment showed both the greatest average DBH and the greatest merchantable volume/acre. The analysis will need to focus on growth after thinning and estimated stand values at age 20.

Table 4.--Residual stand condition and thinning removal description at age 15 by initial spacing treatment.

| | Residual Stand | | | | Thinning Removal | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | 400 | 600 | 800 | 1000 | 400 | 600 | 800 | 1000 |
| DBH (in.) | 7.8 | 7.3 | 6.6 | 6.1 | 7.1 | 6.1 | 6.0 | 5.6 |
| Height (ft) | 53 | 52 | 51 | 50 | 53 | 52 | 51 | 50 |
| BA ($ft^2$/ac) | 80 | 79 | 79 | 77 | 35 | 57 | 71 | 77 |
| TPA | 234 | 262 | 324 | 364 | 126 | 278 | 367 | 444 |
| MVOL (cd/ac) | 19 | 18 | 16 | 14 | 8 | 10 | 12 | 12 |

Table 5.--Stand conditions at age 20 for the unthinned and thinned treatments by initial spacing.

| | Unthinned | | | | Thinned | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | 400 | 600 | 800 | 1000 | 400 | 600 | 800 | 1000 |
| DBH (inches) | 8.4 | 7.3 | 6.9 | 6.4 | 8.9 | 8.5 | 7.6 | 7.0 |
| Height (feet) | 63 | 62 | 61 | 58 | 65 | 64 | 61 | 59 |
| BA ($ft^2$/acre) | 144 | 156 | 174 | 166 | 103 | 98 | 105 | 102 |
| Trees/acre | 356 | 516 | 642 | 713 | 230 | 244 | 318 | 359 |
| MVOL (cd/acre) | 42 | 42 | 45 | 38 | 32 | 29 | 29 | 26 |

By age 20, whether thinned or not, the 400 TPA spacing produced DBH's nearly 2 inches larger than the 1000 TPA and 1 inch larger than the unthinned 600 TPA spacing. Maximum unthinned BA occured in the unthinned 800 TPA spacing. Earlier the peak BA had been at 1000 TPA. Due to 12 percent mortality, the net BA growth of the 1000 TPA treatment had greatly slowed, e.g., 12 $ft^2$/acre in the last 5 years.

Over the last 5 years, mortality in the 400, 600, and 800 spacings was 1, 4, and 7 percent, respectively. As the rotation length increases, it is probable that the 600 (and perhaps finally the 400) TPA spacing will produce the peak BA. Greater MVOL growth occurred on the unthinned treatments ranging from 2.4 to 3.4 cords/acre/year. The thinned treatments produced from 2.2 to 2.6 cords/acre/year.

## WHAT TO OPTIMIZE?

### Pulpwood Only

Now back to the question of which initial planting density and management strategy yields the best return. One approach might be to optimize merchantable volume production. The same result is achieved when all the volume is sold at a flat stumpage as pulpwood. This approach simply multiplies the MVOL by a constant value per cord. The result is in Table 6, where Timber Mart-South stumpage values of $12/cord were used.

Using a single value for stumpage across all of the stand conditions only acknowledges MVOL in cords per acre as the measure of stand value. This results in an equal ranking of the 400, 600, and 800 TPA spacings. The 800 spacing is slightly ahead, but not by a significant margin. The 1000 TPA spacing falls behind by $50-90/acre. This approach, however, ignores the reality of economic constraints and opportunities. Even if wood production were the only organizational goal, low cost production should be considered.

Table 6.--Average stand value at age 20 as pulpwood only.

| Variable | 400 | 600 | 800 | 1000 |
|---|---|---|---|---|
| | ----------$/acre------------ | | | |
| Unthinned | 504 | 504 | 540 | 456 |
| Thinned[1/] | 506 | 501 | 532 | 495 |

[1/]Thinning removal valued as $12/cord and appreciated by 5 years at 5 percent.

### Merchandising Chip & Saw

More factors than MVOL establish the selling price of a stumpage sale. The winning bid will most likely be based on separating out higher valued products such as chip & saw, peeler bolts, and sawlogs. This is well illustrated in a recent article by Greber and Smith (1986). This 20-year-old slash pine stand already offers opportunities for merchandising at least 5 cords/acre of chip & saw logs from the 8-11 inch DBH classes. Fifteen percent of these larger DBH stems were devalued to pulpwood because of disease and stem defect. Table 7 shows the comparisons sorting chip & saw valued at $31/cord.

Table 7.--Average stand value at age 20 sorted as chip & saw and pulpwood.

| Variable | 400 | 600 | 800 | 1000 |
|---|---|---|---|---|
| | ----------$/acre------------ | | | |
| Unthinned | 968 | 792 | 793 | 606 |
| Thinned[1/] | 870 | 844 | 774 | 686 |

[1/]Thinning removal valued as $12/cord and appreciated by 5 years at 5 percent.

The impact of sorting out higher valued products is striking. In the unthinned spacings, the value per acre increased by 30-90 percent over the pulpwood-only analysis. Since the 400 TPA spacing had the largest DBH, it added the most value, $459/acre (through merchandising the larger diameter products). This places the unthinned 400 TPA treatment well ahead of the other alternatives.

The thinning treatment was applied to stimulate diameter growth and create higher valued products. The thinning treatment sufficiently increased chip & saw volumes in the 600 and 1000 TPA spacings to result in values above their unthinned counterparts.

The 400 TPA spacing already produced a large amount of chip & saw without thinning. The value increase will therefore need to occur in the sawlog class. By age 20, only 5 years after the thinning, none of the spacings had enough sawlog volume to merchandise. In future years, perhaps as soon as age 25, the thinned 400 TPA spacing may begin to produce sawlogs and show a financial advantage to thinning.

## Adjusting for Logging Cost

In addition to MVOL and product separation, expected logging cost significantly affects the stumpage value of the stand. Spacing dependent parameters such as cut DBH and cut volume affect the logging cost. To some degree this is accounted for in the price spread between pulpwood and chip & saw. Even within the pulpwood or chip & saw classes, however, there exists enough range in DBH to adjust the stumpage value for variable logging cost.

The Auburn Harvesting Analyzer (1986) was used to establish the estimated logging cost for the pulpwood and chip & saw within each treatment. The stumpage values were then adjusted for logging cost (Figure 1). The pulpwood value of $12/cord was assumed to be based on an average DBH of 7 inches. The chip & saw value of $31/cord was assumed to be based on an average DBH of 10 inches. If the chip & saw occurring within a treatment averaged less than 10 inches, the difference in logging cost between that DBH and the 10 inch average was subtracted from the stumpage value. If the treatment DBH was greater than the 10 inch average, the difference was added to the stumpage. Table 8 shows the result of adjusting pulpwood and chip & saw stumpage for logging cost.

Figure 1. **LOGGING ADJUSTED STUMPAGE**

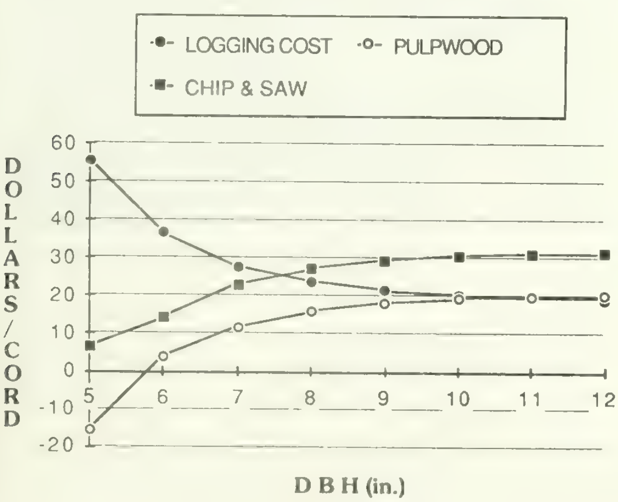


Table 8.--Average stand value at age 20 sorted as chip & saw and pulpwood and adjusted for logging cost.

| Variable | 400 | 600 | 800 | 1000 |
|---|---|---|---|---|
| | ----------$/acre------------ | | | |
| Unthinned | 824 | 583 | 499 | 205 |
| Thinned[1/] | 810 | 639 | 506 | 275 |

[1/]Thinning removal valued as $12/cord and appreciated by 5 years at 5 percent.

Across all spacings and thinning treatments the values fell from the previous estimates when chip & saw was merchandised without considering logging cost. This results primarily from the average cut DBH being less than the 10 inch average for chip & saw. The stumpage fell accordingly from $31/cord. The reduction in stand value is greater as the initial spacing increased from 400 to 1000 TPA, i.e., from about $100/acre to more than $400/acre. The unthinned 400 TPA treatment still generates the greatest value.

The logging cost adjustment may also be applied when pulpwood is the only product. In this case the average cut DBH may be above or below the 7 inch index diameter. The unthinned 400 and 600 TPA received a premium above the $12/cord average stumpage. The unthinned 800 and 1000 TPA were both devalued for the small average diameters. This changes the ranking of TPA from flat, as in Table 6, to a strong trend (Table 9). The 400 TPA planting is more valuable whether thinned or not because it is cheaper to harvest.

## Further Steps of Analysis

As additional data is gathered on this study, the impact of merchandising sawlogs will add a new dimension to product separation. Other steps are available to further refine the process of estimating the value of future stands of timber.

Table 9.--Average stand value at age 20 for pulpwood only adjusted for logging cost.

| Variable | 400 | 600 | 800 | 1000 |
|---|---|---|---|---|
| | ----------$/acre------------ | | | |
| Unthinned | 714 | 554 | 499 | 254 |
| Thinned[1/] | 721 | 554 | 469 | 247 |

[1/] Thinning removal valued as $12/cord and appreciated by 5 years at 5 percent.

Sawlog grade is affected by natural pruning. Natural pruning is likewise altered by initial planting density. Therefore, high density spacings that would prune earlier may be more valuable through higher sawlog grade. The issue of natural pruning at lower initial planting densities is even more critical for loblolly pine where live crown and dead branches persist lower on the bole than for slash pine.

These additional refinements may affect the current superiority of the unthinned 400 TPA. With age the thinning treatment should gain an advantage. Once sawlog grade is a factor, the thinned 600 TPA may become very competitive for the top position. The spacing debate will continue, however, because the market value of sawlogs will fluctuate and different organizations will use different appreciation rates for future value calculations. Hopefully some of these ideas will add to the accuracy in ranking silvicultural options.

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# Federal Income Tax Treatment of Silvicultural and Related Costs Associated With Intermediate Stand Management[1]

William C. Siegel[2]

Abstract.--Many silvicultural and related practices are associated with the intermediate management of southern forests. To partially recover the costs of such activities on a federal income tax return, the expenditures must be either capitalized or deducted as operating costs. The correct and optimal procedure, whether mandatory or optional, depends on a number of factors. The current (1986) law governing this area of the federal income tax law is discussed, followed by an analysis of how procedures will change in 1987 under provisions of the 1986 Tax Reform Act.

Keywords: Expensing, capitalization, business, investment, stand maintenance, stand establishment

Many silvicultural and related practices are utilized by foresters in the management of southern forests. Such practices are employed during both stand establishment and intermediate management. Some, depending on the silvicultural system, are also used during the pre-harvest stage. The Internal Revenue Code permits recovery of part of the costs of these activities if reported on the landowner's federal income tax return. To recover silvicultural and related expenses, they must be either capitalized or deducted as operating expenditures. The latter procedure is often called "expensing."

The extent of savings depends on which of these methods is used and the timing of the practice. The correct or optimal tax procedure, whether mandatory or optional, in turn depends on: (1) what the practice is, (2) its purpose, and (3) the taxpayer's tax status and cash-flow position. Being able to treat a particular silvicultural expenditure in a certain way for federal income tax purposes, as opposed to another way, may mean the difference between the activity being cost-effective or not. Recent tax law changes have further added to the confusion.

The distinctions between capitalization and expensing, and between stand establishment and intermediate management, are reviewed herein. The present (1986) law concerning the federal income tax treatment of silvicultural and related costs associated with intermediate stand management is also discussed. Finally, the changes indicated by the 1986 Tax Reform Act are addressed. Guidelines are presented to assist managers and landowners in making the proper federal income tax determinations.

[1]Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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## COST RECOVERY PROCEDURES

Capitalization and expensing are authorized in general terms by the Internal Revenue Code. The statute makes no specific mention of timber, nor of any other particular enterprise or asset.

### Capitalization

Section 263 of the Internal Revenue Code provides that amounts expended for real estate and equipment used for business or investment purposes or for making improvements that increase the value of such property -- including forest land and standing timber -- are nondeductible capital costs.[3] The test to be met is that the benefits of capital expenditures must be either permanent or those that will last for a determinable period of more than 1 year. Such costs must be capitalized -- that is, they must be segregated into a capital account. They are generally not recoverable immediately, but rather are deducted from income over a period of time as the capital asset or improvement with which they are associated is sold, used up, or worn out. The precise procedures employed to recover capital costs vary, depending on the nature and useful life of the asset acquired or the practice undertaken. Capitalized silvicultural and related expenditures are treated in one of two ways -- deducted from sale proceeds or amortized.

#### Deduction from Sale Proceeds

Deduction of a capitalized expenditure from sale proceeds is usually the least desirable recovery method from the taxpayer's standpoint. However, this procedure must be followed for items with a permanent or indeterminable life or for practices

[3]The term "nondeductible" as used here does not mean that such costs are not deductible per se, but rather that they cannot be taken as a current deduction in their entirety in the year they are incurred.

with a permanent benefit. Not only is the deduction deferred until the asset is sold (sometimes a period of many years), but before 1987 it usually offset a long-term capital gain that was taxed at a much lower rate than was ordinary income.

### Amortization

Capital expenditures not associated with machinery or equipment or not otherwise depreciable, but which add value to a capital asset by providing a determinable nonpermanent benefit of more than a year's duration, may be amortized. That is, they may be deducted in annual installments over the life of the benefit or, in some instances, over another specified period of time. These deductions may be offset against ordinary income from any source.

### Expensing

As authorized by Sections 162 and 212 of the Internal Revenue Code, expenditures categorized as operating costs may be deducted in full from ordinary income from any source (expensed) in the year they are incurred. These expenses -- sometimes referred to as "ordinary and necessary" costs -- are those generally related to the income potential of the property (Briggs and Condrell, 1980; U.S. Department of Agriculture 1982). Expensing is more advantageous than capitalization because the entire deduction is taken in the year that the cost is incurred and may always be offset against ordinary income from any source. The return of capital is immediate -- a dollar saved today is more valuable than one saved later.

## CAPITALIZATION VERSUS EXPENSING OF SILVICULTURAL AND RELATED COSTS

How should the costs of specific silvicultural and related practices be treated on the federal income tax return? All those costs directly associated with stand establishment are capital expenditures and must be capitalized.[4] Included are costs incurred for the purchase of standing trees, site preparation, direct seeding, planting, and any practices necessary to ensure seedling survival and establishment -- that is, a free-to-grow status.

On the other hand, most silvicultural and related expenses incurred for maintenance and improvement of an established stand (intermediate stand management) or for stand protection, are usually considered to be current operating costs -- that is, ordinary and necessary expenditures -- and thus expensable. There are, however, some exceptions to this general rule. For example, even though particular machinery or equipment costs may be incurred in association with intermediate stand management, they are nevertheless considered capital items and must be capitalized. All property taxes and interest, whether associated with stand establishment or intermediate management, are expensable. All costs eligible for expensing may -- at the taxpayer's option -- be capitalized as "carrying charges" instead of being expensed and thus deducted from sale income when the timber is cut or sold.[5]

### Recovery of Stand Establishment Costs

Before 1980, capitalized stand establishment costs could only be recovered as a deduction from sale proceeds when the timber was cut or sold. This type of recovery is not nearly as advantageous as a more timely deduction from ordinary income from any source.

Since 1980, however, the first $10,000 of annual stand establishment costs, even though capitalized, have been recoverable by amortization before the trees are cut or sold. A fiction in the law was created, setting the useful life of the trees at 7 years. The qualifying expenditure is amortized over 8 tax years, beginning with the year the cost was incurred. One-fourteenth of the expense is deducted that year, one-seventh during during each of the next 6 years, and the remaining one-fourteenth in the eighth year. These deductions may be taken whether or not the taxpayer itemizes deductions on his or her tax return. In addition, a 10-percent tax credit is also allowed (10 percent of a maximum of $10,000 per year). No changes were made in the amortization or credit provisions by the 1986 Tax Reform Act.

The amortization and credit provisions are separate tax return elections. Either or both can be selected or rejected. If the taxpayer, for some reason, chooses not to amortize qualifying expenditures, they may be recovered by capitalizing in the traditional way -- as an offset when the timber is cut or sold. In any event, all establishment costs in excess of $10,000 per year must also be recovered by that method.

### Stand Establishment Versus Stand Maintenance

When does stand establishment end and intermediate management (stand maintenance) begin for federal income tax purposes? Some silvicultural situations obviously fall into the establishment category and some into the intermediate management category. With others, however, the law is less clear, and it is sometimes a major problem to determine whether a silvicultural activity is legally part of the stand establishment process or, alternatively, is associated with maintaining and improving an established stand. There are no "hard and fast" rules. In many respects, this is a gray area of the tax law. Often the distinction is not clear and depends on a number of factors, all of which must be considered.

Sometimes a single practice may fall into both categories at the same time and thus serve a dual purpose. An allocation may then be made between expensing and capitalization, with the cost

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[4] Treasury Regulation 1.611-3(a).

[5] Internal Revenue Code Sections 265-266; Treasury Regulation 1.266-1.

proportionately divided. Removal of cull or low-value trees in a mixed-age stand containing both older trees and young seedlings is an example of such a situation. The tree removal could perhaps be necessary for seedling survival while enhancing the growth of the established trees. Prescribed burning in such a stand could also serve the dual purpose of site preparation and fire protection.

A detailed discussion of this particular area of the tax law is beyond the scope of this paper. For an in-depth treatment, see Siegel (1984).

## EXPENSING INTERMEDIATE MANAGEMENT COSTS

With this background, the details of expensing those silvicultural and related costs clearly associated with intermediate stand management are examined. Such expenditures include, but are not limited to, those incurred for various timber stand improvement practices such as hardwood or cull tree deadening, brush control, cleaning, weeding, and noncommercial improvement cuts; fire, insect, disease, and mammal protection; pre-commercial thinning; prescribed burning; and pruning (Cox 1984, Briggs and Condrell 1980). The procedures permitted under current (1986) law are discussed first, followed by an analysis of how these will be changed beginning in 1987 under provisions of the 1986 Tax Reform Act.

### Current Expensing Law

Under current law, silvicultural and related costs associated with intermediate stand management may be deducted in full from ordinary income from any source (expensed) in the year they are incurred. If the costs are associated with a timber business, they may be deducted on Schedule C or Schedule F of Form 1040, or on the appropriate corporate or partnership schedules, as a business expense.[6] If the deductions result in a loss, the loss may generally be carried forward to offset income in a subsequent tax year. Property taxes and interest are also fully deductible for timber businesses each year.

Somewhat different rules apply to timber investments. If silvicultural and related costs are associated with a timber investment, they may be deducted only as a "miscellaneous itemized deduction" on Schedule A of Form 1040.[7] To utilize this procedure, however, the taxpayer must itemize deductions on his or her tax return. In years when deductions are not itemized, such costs must be capitalized or they will be permanently lost. Property taxes and interest are also fully deductible each year for timber investors who itemize their deductions.

It is beyond the scope of this paper to discuss the complex differences between a timber investment and a timber business. There are no clear rules. Nevertheless, it can generally be said that a business entails considerably more activity than does an investment. However, extensive silvicultural practices alone do not equate to a business -- other factors also have to be considered. In the final analysis, each individual situation stands on its own and must be examined separately to make the distinction.

To expense timber related costs, it is not necessary that the property be currently producing timber income. The owner, however, must have a profit motive. The Internal Revenue Service (IRS) will automatically assume such a motive and not question legitimate deductions if there is a profit in at least 2 out of every 5 consecutive years.[8] Failure to meet this standard, however, is not necessarily indicative of the lack of a profit motive. The term "profit" can be limited to appreciation in value and is the criterion often used for timber activities that may produce no income for periods of many years.

### Changes Made by the 1986 Tax Reform Act

Beginning in 1987, the procedures described above will be drastically changed for certain taxpayers by provisions of the 1986 Tax Reform Act. The new rules applicable to expensing of silvicultural and related costs associated with intermediate stand management pertain to three categories of taxpayers (Siegel 1987). These are: (1) active timber businesses, (2) active timber investors, and (3) passive participants in either a timber investment or a timber business.

#### Active Timber Business

All silvicultural and related costs, including property taxes and interest, will be fully deductible each year as incurred against income from any source. There are no changes from prior law.

#### Active Timber Investor

The expensing of silvicultural and related costs, property taxes, and interest will each be treated differently for active timber investors. Silvicultural and related costs will be deductible each year against income from any source only to the extent that -- when added together with the taxpayers's other "miscellaneous itemized deductions" -- the total exceeds 2 percent of adjusted gross income. To the extent that test cannot be met, such expenditures must either

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[6] Sections 161-162 of the Internal Revenue Code allow both corporate and individual businesses to deduct all "ordinary and necessary expenses."

[7] The authority in Section 212 of the Internal Revenue Code, relating to expenses of producing income from, or in managing and conserving, non-business investment type property held by individuals. Section 212 contains language similar to that in Sections 161-162.

[8] This is popularly termed the "hobby loss rule." Under the 1986 Tax Reform Act, effective in 1987, the rule will require a profit in at least 3 out of every 5 consecutive years.

be capitalized or lost. The deductibility of interest attributable to indebtedness associated with a timber investment has also been severely curtailed. Such interest will be deductible each year only to the extent of the taxpayer's total investment income (timber plus nontimber) for that year. It may no longer be used to offset income from other sources in years when there is no investment income. Unused interest deductions, however, may be carried forward indefinitely to subsequent tax years in which there will be investment income. With respect to property taxes, there are no changes from prior law. Timber investors may continue to expense property taxes in full each year as an itemized deduction against income from any source.

Beginning in 1987, the distinction between a timber business and a timber investment will unquestionably become more significant with respect to the expensing of timber related costs. Currently, it is not known how the IRS will address the question. It may promulgate specific regulations directed to timber activities or continue to rely on the general law to make the distinction.

### Passive Participant

Passive participants in a timber business or investment will be faced with formidable expensing restrictions. Silvicultural and related costs, property taxes, and interest will all generally be deductible each year only to the extent of passive income (total from all sources) during that year. None of these types of expenditures may be used to offset nonpassive income except in the case of certain closely held corporations.[9] The new limitations generally apply in full to tax years beginning after 1986. However, a 5 year phase-in is provided for passive interests already held on the date of enactment of the new tax law. Under the phase-in rules, partial deductions will be allowed from 1987 through 1990, with full exclusion beginning only in 1991.

How does active involvement differ from a passive interest? The answer is not yet clear because the IRS has yet to write the regulations interpreting this section of the new law. It has, however, indicated that the forthcoming regulations will specifically address timber holdings. The legislation does state that active participants must materially participate in the activity and that material participation must include active involvement in making management decisions on a regular, continuous, and substantial basis.

[9] Closely held C corporations that are not personal service corporations may offset passive losses (deductions) against net active income in addition to passive income, but not against portfolio income. A closely held C corporation is any C corporation in which more than 50 percent of the stock value is owned by five or fewer individuals during the last half of the tax year.

## CONCLUSION

Just as with prior law, the federal income tax status under the 1986 Tax Reform Act of some silvicultural and related expenditures is clear and the status of certain other such costs is not. Also, as under previous law, the correct or optimal method of handling such expenditures for tax recovery under the new legislation depends on a number of different factors. These include the nature, timing, and purpose of the practice or cost; the taxpayer's cash flow situation; his or her tax status; and the available tax options.

With respect to the costs associated with intermediate stand management, the preferred status under the new law seems to be an active participant in a timber business. Many nonindustrial woodland owners, however, will not be able to qualify for this classification. Some will undoubtedly lose deductions altogether or at best have to postpone them to future years. When coupled with the much higher taxes on timber income that will prevail beginning in 1987, this situation will certainly mean that less silvicultural work will be performed in the nonindustrial sector. In order to minimize the negative impacts of the new restrictions on expensing of silvicultural and related costs, proper planning will be more important than previously. The key will be to know the technical facts of each silvicultural operation, to be cognizant of the changes made by the new law and how they apply to each taxpayer's personal and forestry situations, and to then interphase the two for maximum advantage.

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# PRODUCTION AND COSTS OF THE BELL MODEL T FELLER-BUNCHER[1]

Joe McNeel and W. Dale Greene[2]

Abstract.--The Bell Model T feller-buncher is a tricycle-frame machine which employs a chainsaw felling head attached to a dangle boom. Although unable to hold a severed tree upright, the machine is adept at bunching all but the largest trees which it can cut. Results of a production study of the Bell Model T equipped with a 24 inch felling saw are presented illustrating the effects of stand parameters on machine performance and costs.

## INTRODUCTION

The Bell Model T is one of several recently introduced feller-bunchers designed to eliminate shear-related damage in harvesting sawtimber. The unit uses a chainsaw felling head, rather than the more conventional hydraulic shear, to fell trees up to 24 inches in diameter at groundline. The chainsaw head eliminates the occurrence of compression damage and splits that commonly result when using shears.

Unlike other saw type feller-bunchers, the Bell requires a low capital investment. This appeals to many loggers faced with the choice of either buying a saw type feller-buncher or using sawyers to fell sawtimber size trees.

Because the Bell is relatively new in the United States, a study was undertaken to determine its production and cost characteristics under typical operating conditions.

## MACHINE DESCRIPTION

The Bell Model T is a tricycle wheel carrier combined with a hydraulic powered chainsaw head. The three wheeled carrier manufactured by Bell is very similar to the Mor-Bell feller-buncher (Stokes et al, 1982). A summary of the machine characteristics are presented below.

Bell Carrier:

| | |
|---|---|
| Length: | 189 inches |
| Width: | 104 inches |
| Engine: | 70 HP Deutz, air-cooled |
| Height: | 105 inches |
| Turning Radius: | 189 inches |
| Tire Size: | 23.1 x 26 |
| Ground Clearance: | 22 inches |

Bell Felling Head:

Type: Directional Chainsaw (270° Rotation)
Felling Capacity: 24 inches Diameter at Groundline
Bunch Capacity: 1 Tree per Turn

## STUDY METHODS

The Bell Model T was observed during July 1986 while felling for a production logging operation owned by the Gray Lumber Company of Waverly, VA. The logging company operation had used the Bell for approximately 3 months prior to the study. System production averaged between 80 and 120 cords per day during the study with felling performed exclusively by a single Bell machine.

The study site was located in Sussex County, VA and was typical of the lower coastal plain with less than 5 percent slope. Six plots were installed on the site prior to harvest. Plots were of a variable size, but usually covered an area of approximately 1 acre. Trees in each plot were measured to determine location within the plot and DBH. Trees were given unique numbers for identification during the time study of felling activities. Trees from each plot were subsampled for total height and diameter at groundline (DGL).

The harvested stand was loblolly pine of natural origin, averaging 100 trees per acre. Trees ranged in diameter from 6 to 24 inches DBH and averaged 13.3 inches. total height averaged 70 feet. A summary of collected plot data is provided in Table 1.

Table 1.--Stand characteristics measured from the study plots.

| Variable | No. of Obs. | Mean | Std. Dev. |
|---|---|---|---|
| DBH (inches) | 322 | 13.28 | 3.29 |
| DGL (inches) | | 17.01 | 4.15 |
| Ttl. Height (ft) | | 71.48 | 6.43 |
| Volume/Tree ($ft^3$) | | 33.93 | 18.25 |

A video camera equipped with an internal stopwatch was used to record the Bell during felling.

[1]Presented at the Fourth Biennial Southern Silviculture Research Conference

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activities. The recorded videotapes were later viewed to obtain elapsed function times and associated tree numbers within each plot.

Four elements of the machine work cycle were identified. These included: (1)move to tree, (2)positon and sever, (3)bunching, and (4)bunch maintenance.

Statistical analysis of the time study data was conducted using linear regression techniques to produce prediction equations for elemental times. A total cycle equation was then developed by adding the elemental equations. Hourly ownership and operating costs of the Bell were estimated using market prices during the summer of 1986 with the machine rate approach described by Miyata (1980).

## RESULTS

A total of 322 cycles were analyzed. The time required for the position and sever element averaged 0.159 minutes per tree, while the move to tree element averaged 0.255 minutes per tree. Bunching averaged 0.124 minutes per tree for 320 observations and bunch maintenance averaged 0.313 minutes per bunch for 21 observations. A summary of the elements observed in the study is provided in Table 2.

Table 2.--Summary of elemental cycle data for the Bell Model T.

| Element | Number of Obs. | Mean | Std. Dev. | ---Range--- Min. | Max. |
|---|---|---|---|---|---|
| | | -----(minutes | per tree)---- | | |
| Position and Sever | 322 | 0.159 | 0.083 | 0.051 | 1.123 |
| Move to Tree | 322 | 0.255 | 0.178 | 0.043 | 1.228 |
| Bunch | 320 | 0.124 | 0.092 | 0.033 | 0.652 |
| Bunch Maintenance | 21 | 0.313 | 0.158 | 0.123 | 0.625 |

### Position and Sever Element

The time required to position and fell a tree during the study was relatively constant for trees of less than 20 inches DBH (Fig. 1). Trees 20 inches or larger required approximately twice as much to fell.

Observations indicated that, at a groundline diameter of 24 inches (DBH of approximately 21 inches), the felling head must be repositioned on the tree in order to make a complete cut. The machine is thus required to perform the position and sever element twice when felling trees over 21 inches at DBH.

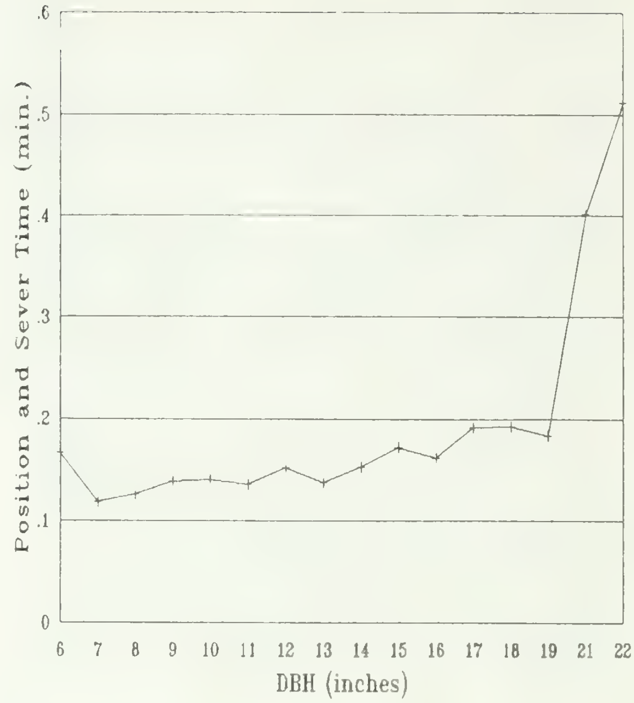


Figure 1.--Comparison of mean position and sever times by DBH class.

Regression analysis of the position and sever data produced a prediction equation based on $DBH^2$. No other variable was found to be significant in the analysis. The prediction equation for the position and sever element follows:

$$PS = 0.08506 + 0.0003983\ (DBH^2)$$

$r^2 = 0.1760$ F-Value = 67.93
Where:
PS = Position and sever time (minutes/tree)
DBH = Diameter at breast height (inches)

The F-value for DBH was significant at the 0.001 level, suggesting that DBH is a good estimator for position and sever times. However, the low $r^2$ value indicates a high level of variability in the data that cannot be explained by the prediction equation.

### Move to Tree Element

Move to tree elemental times were also modeled with a regression estimator. Move distance proved most significant in the regression analysis and was used to develop a prediction equation. The equation for estimating move to tree element times follows:

$$MT = 0.1409 + 0.003196\ (DIST)$$
$r^2 = 0.1885$ F-Value = 61.55
Where:
MT = Move to tree time (minutes/tree
DIST = Distance between trees (feet)

Although distance was highly significant in explaining variability in between tree movement, the data was too variable to produce a high $r^2$ value. No other variable tested reduced move time variability in a significant manner.

To make the prediction equation more useful, the variable DIST was replaced by a variable approximating between tree distance in terms of stand density, as suggested by Ashmore and others (1983) in a similar study. The resulting equation follows:

$MT = 0.1409 + 0.6670(N)^{-\frac{1}{2}}$
Where:
MT = Move to tree time (minutes/tree)
N = Stand density (trees/acre)

Bunch Element

Mean bunch times continuously declined as tree size increased, suggesting that large diameter trees were not bunched. A graph of mean bunch times by DBH indicates that trees of 18 inches at DBH and larger required less than 0.08 minutes to bunch (Fig. 2). The Bell, weighing less than 12,000 lbs., was unable to manipulate the larger diameter trees into multiple stem bunches.


Figure 2.--Comparison of mean bunch times by DBH class.

The bunch element proved too variable to predict with regression. Instead, a mean of 0.124 minutes per tree, derived from the study data, was used to estimate bunch times in the machine cycle.

Bunch Maintenance Element

Bunch maintenance occurred only 21 times in 322 observed cycles. No variable in the study significantly accounted for variability in this data and it was not possible to predict when this element would occur. As a result, a weighted mean was used to account for bunch maintenance within the total cycle.

Approximately once every 15 turns, bunch maintenance occurred and lasted an average of 0.32 minutes. With a weighted mean approach, 0.019 minutes were added to the total cycle time to account for bunch maintenance.

Total Cycle Time

A prediction equation estimating total cycle time was developed by combining elemental time estimators. The prediction equation requires 2 input variables, DBH and stand density, to predict individual cycle times. The prediction equation for total cycle time follows:

$TC = 0.36996 + 0.6770(N)^{-\frac{1}{2}} + 0.0003983(DBH)^2$
Where:
TC = Total cycle time (minutes/tree)
N = Stand density (trees/acre)
DBH = Diameter at breast height (inches)

This equation was used with measures of stand density and average stand diameter to predict the range of productivity for the Bell. The graph in Figure 3 illustrates this range based on stand values ranging from 6 to 22 inches.

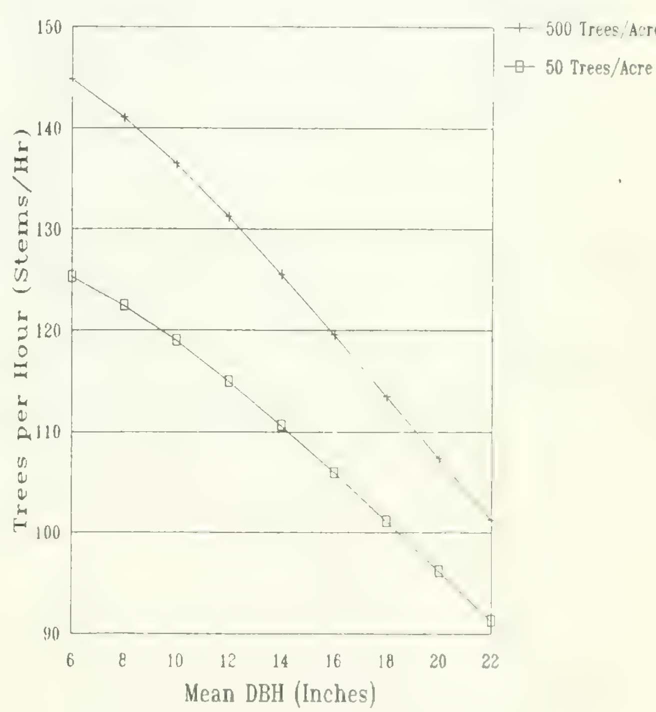


Figure 3.--Predicted production rates for the Bell Model T.

## COST ANALYSIS

A cost analysis of the Bell was conducted using the prediction equation for total cycle time and an hourly cost estimate based on current cost data. The analysis incorporated the machine rate to develop hourly cost estimates for the unit. Hourly ownership and operating costs estimates for the Bell Model T were based on machine rate calculations:

| | | |
|---|---|---|
| Assumptions: | | |
| Purchase Price: | $15,000 | |
| Salvage Value: | $11,000 | |
| Economic Life: | 3 years | |
| Utilization: | 65 percent | |
| Scheduled Machine Hrs (SMHrs) per Yr: | | 2000 |
| Productive Machine Hrs (PMHrs) per Yr: | | 1300 |
| Ownership Costs: | | |
| Depreciation: | $11.28 | |
| Taxes, Interest and Insurance (25 pct. of AVI) | 7.76 | |
| Total Ownership Costs: | $19.04 per PMHr. | |
| Operating Costs: | | |
| Fuel (1.75 GPH @ $0.50/gal.) | 0.88 | |
| Lube, oil and filters (30 pct. of fuel cost) | 0.26 | |
| Repair and maintenance (60 pct. of depreciation) | 6.77 | |
| Labor ($7.50/sched. hr. and 36 pct. fringe benefits) | 15.70 | |
| Total Ownership Costs | $23.61 per PMHr. | |
| | $27.72 per SMHr. | |

Cost of per cord prediction for the Bell were developed based on hourly productive cost estimates (Fig. 4). As average stand diameter increases, the cost of harvesting with the Bell is projected to decline. In contrast, little change in cost occurs relative to stand density.

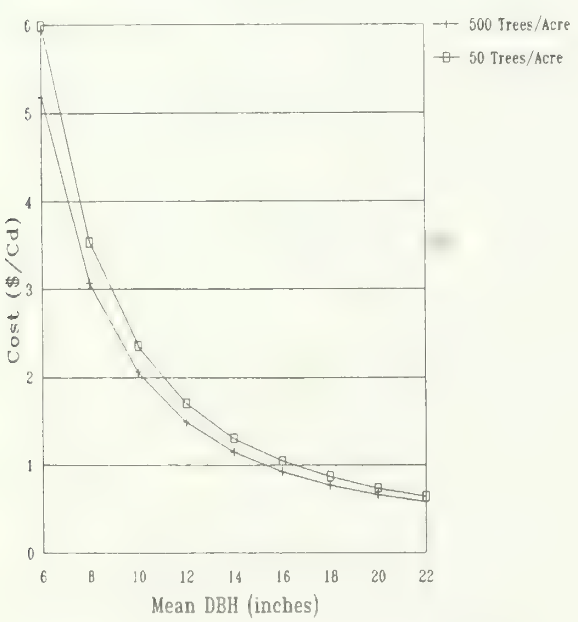


Figure 4.--Cost predictions for the Bell Model T.

For example, harvesting a stand of timber averaging 500 trees per acre with a mean DBH of 6 inches was estimated to cost $5.15 per cord. A stand averaging 50 trees per acre with a mean DBH of 12 inches was estimated to cost $1.70 per cord, a decrease of more than 65 percent in per unit costs.

## CONCLUSIONS

The Bell Model T is a unique feller-buncher designed as a low cost alternative to conventional feller-bunchers using hydraulic shears. The unit worked effectively in pines ranging in size from 6 to 22 inches at DBH during a time study analysis.

Elemental and total cycle predictors were developed from the time study data. Production estimates suggest that production rates for the Bell are most affected by stand diameter.

The cost and production analysis results suggest that the Bell would not be as effective in thinnings or in clearcuts where the average stand diameter falls much below 10 inches at DBH. Costs ranged between $0.50 and $2.00 per cord for stands with an average diameter greater than 10 inches in DBH, but increased to over $5.00 per cord in stands averaging less than 8 inches DBH.

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PRODUCTIVITY AND COST OF GRAPPLE SKIDDERS

PERFORMING GATE DELIMBING[1]

R. A. Tufts, D. L. Sirois, and B. J. Stokes[2]

Abstract.--Time study data were collected on six different types of rubber-tired, grapple skidders performing skidding and gate delimbing. Regression analysis was used to develop a model to predict total cycle time. The total cycle time model was used to demonstrate the importance of the variables affecting productivity. Cost per cord was calculated for each of the six machines.

## INTRODUCTION

Timber harvesting is a silvicultural tool as much as site preparation and timber stand improvement. To effectively use this tool the forest manager must understand the factors that affect the cost and productivity of timber harvesting. The value of a stand of timber is the residual of delivered price less harvesting cost. To maximize the value of the timber, harvesting costs must be minimized. The only way to reduce costs is to understand the variables that affect harvesting and plan operations to minimize the cost of these variables.

Timber harvesting methods have evolved from labor-intensive, low-capital systems to highly mechanized, highly capitalized systems. This change has been brought about by the decline in the availability of woods labor and the need for increased productivity. A recent survey (Weaver et al. 1981) indicated that slightly less than two-thirds of all pulpwood harvested by independent contractors was produced by 25 percent of the contractors because of the increase in mechanized operations.

The most common inwoods system for mechanized timber harvesting operations in the South consists of feller-bunchers; rubber-tired, grapple skidders; and delimbing gates. This system is highly productive because of the equipment, and relatively safe because no manual operations are performed in the woods.

In-woods transportation and delimbing are performed by the skidder. Multiple trees are placed in a bunch by the feller-buncher. The bunch is transported to the log deck by the skidder with an intermediate stop at the delimbing gate. The delimbing gate consists of a grid assembly made of pipe. The trees are backed through the gate to break the limbs off the stem (Figure 1).

Figure 1.--A grapple skidder load being backed through a delimbing gate.

The high degree of capitalization and increased competition create the need for careful analysis of harvesting operations. Analysis is even more important when using a skidder for gate delimbing because load sizes must be smaller. Stokes and Lanford (1985) reported that it was feasible to gate delimb only small loads when thinning young pine plantations.

## LITERATURE REVIEW

Variables that affect skidder productivity can be divided into three categories: machine variables, load variables, and stand variables. The most important variables affecting skidder productivity are load size and skid distance. Tufts (1977) and Plummer (1977) tabulated skidder productivity according to skid distance

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and tree size. Fowler (1972) derived a prediction equation based on skid distance, volume per acre, and grapple payload. Gardner (1978) determined that the principal variables affecting cycle time for skidders were skid distance, number of logs or load size, and weight of the machine.

A comprehensive list of variables was compiled by Sampson and Donnelly (1977). They listed skid distance, horsepower, maximum speed in each gear, percent slippage of wheels, volume per acre, number of pieces to be skidded per acre, density of the residual stand, slope, and soil surface conditions as variables that affect skidder productivity. The current use of wider tires in skidding operations can also affect skidder productivity (Rummer and Sirois 1984). Lanford and Haver (1973) developed a series of prediction equations based on skid distance, machine size, slope, dbh, volume per acre, and soil conditions. Liu (1981) found that brushiness, obstacles, and the number of stems per load did not significantly affect production. He identified horsepower, skidder weight, load volume, slope, and skid distance as the primary variables in predicting skidder productivity.

## METHODOLOGY

Time study data were collected on six different types of rubber-tired, grapple skidders performing skidding and gate delimbing. Each cycle was divided into the following elements: travel empty, grapple, travel loaded-full tree, gate delimbing, travel loaded-tree length, and ungrapple. Individual elements were timed and the elemental times were added to produce the total cycle time.

Independent variables measured for each cycle consisted of machine, load, and stand variables. Machine variables considered were weight, horsepower, and a ratio of weight divided by 1,000 divided by horsepower. Load variables measured were weight, volume, average volume per tree, basal area, average basal area per tree, number of trees and number of bunches. Stand variables recorded were skid distance, slope perpendicular to the contour, direction of travel in relation to slope, brush conditions, and soil strength.

Linear regression analysis (Draper and Smith 1967) was used to develop a model to predict total cycle time as a function of the independent variables. Correlation coefficients were calculated to identify the most significant variables affecting cycle time. Models were developed by starting with the independent variable that explained the most variation. Then, successive variables and interaction terms were added until the addition of another variable would not significantly improve the model as measured by the partial F-statistic.

The best model was used to determine the effect of the significant variables on time per cycle and productivity. Time per cycle was generated by the model. Productivity was calculated as the cords skidded and delimbed per scheduled machine hour. To calculate productivity, load size in pounds was divided by 5,400 pounds per cord and multiplied by the number of cycles per scheduled machine hour (SMH), based on 75-percent utilization.

Cost per cord as a function of load size was calculated for each of the six types of machines. Productivity for each machine type was calculated with the model using a skid distance of 650 feet and the machine's ratio, the average number of bunches and range of load sizes.

Machine costs were calculated using the machine rate method (Miyata 1980). List prices were obtained from local equipment dealers. Depreciation was calculated on a straight line basis, using a 5-year life and 20-percent salvage value. Annual interest, insurance, and taxes were based on 18 percent of the average annual investment. Fuel costs were $1.00 per gallon and usage was based on 0.028 gallons per horsepower-hour (Plummer and Stokes 1983). Lubrication costs were 30 percent of fuel cost. Maintenance and repair costs were estimated to be 80 percent of depreciation. Fuel, lubrication, maintenance and repair accumulate on a productive machine hour (PMH) basis and were converted to a scheduled machine hour basis by multiplying by the utilization rate. Labor including fringe benefits totaled $9.10 per SMH. The machine rate was divided by the productivity as a function of load size to obtain the cost per cord.

## RESULTS

The data set consisted of a total of 207 cycles collected during 11 studies on six different types of machines. Machine types are listed in Table 1. The independent variables measured and their averages and ranges are listed in Table 2.

Table 1.--Machine types studied, their horsepower, weight, and number of observations.

| Machine type | Horsepower | Weight (lb.) | Number of observations |
|---|---|---|---|
| Timberjack 520[a] | 185 | 29,000 | 42 |
| Tree Farmer C7 | 136 | 22,600 | 13 |
| Timberjack 380 | 136 | 20,500 | 15 |
| Caterpillar 518 | 130 | 25,300 | 35 |
| Franklin 170 | 121 | 22,340 | 46 |
| John Deere 540B | 96 | 18,675 | 56 |

[a]Brand names are listed for the reader's benefit and do not constitute an endorsement by the authors or their organizations.

Machine variables are constant for each machine and represent typical skidders in use on timber harvesting operations.

Table 2.--Independent variables measured and their averages and ranges.

| Variable | Average | Range |
|---|---|---|
| Machine variables | | |
| Weight, lb. | 23,083 | 18,675 - 29,000 |
| Horsepower | 131 | 96 - 185 |
| Ratio (wt/1000/Hp) | 0.180 | 0.151 - 0.195 |
| Load variables | | |
| Weight, lb. | 3,218 | 518 - 8,289 |
| Volume, cu. ft. | 50 | 7 - 122 |
| Avg. Vol./tree | 8.26 | 1.27 - 28.00 |
| Basal area, sq. ft. | 2.69 | 0.40 - 6.90 |
| Avg. BA/tree | 0.43 | 0.08 - 1.25 |
| No. of trees | 7.33 | 1 - 22 |
| No. of bunches | 1.15 | 1 4 |
| Stand variables | | |
| Travel distance, ft. | 656 | 185 - 2,488 |
| Slope | | |
| Steepness, % | 5.5 | 0 - 20 |

Load variables exhibit a wide variation as would be expected. Load weight averaged 3,218 pounds or about 0.6 cord. Ten percent of the loads were less than 0.3 cord, and only 8 percent of the loads were larger than 1 cord. The average basal area represents a tree 8.9 inches in dbh, with a range of 3.9 to 15.1 inches in dbh. The average number of bunches per cycle was 1.15; however, three of the machines never grappled more than one bunch, and only one machine grappled more than two. Since load size and number of bunches should be independent, any bunch size can be built; picking up more than one bunch represents inefficiencies for the skidder.

Of the stand variables, only skid distance was significant. Skid distances as high as 2,488 feet were observed, but 86 percent of the observations were less than 1,000 feet. Slope should affect skidder cycle times, but during this study most of the observations were on flat terrain; the average slope was only 5.5 percent with a maximum of 20 percent. Brush and soil conditions were assigned qualitative values, but the range of conditions observed were not sufficient for either of these to be significant.

The model which best predicted total cycle time for rubber-tired, grapple skidders performing skidding and gate delimbing was as follows:

$$\begin{aligned}\text{Time/cycle} = {} & 7.237 - 0.009081 \times \text{Distance} \\ & + 0.001497 \times \text{Load} \\ & - 30.79 \times \text{Ratio} \\ & + 0.05557 \times \text{Distance} \times \text{Ratio} \\ & - 0.006355 \times \text{Load} \times \text{Ratio} \\ & + 0.001624 \times \text{Distance} \times \text{No. Bunches} \\ & - 0.000133 \times \text{Load} \times \text{No. Bunches}\end{aligned}$$

where: $R^2 = .81$

where: Distance = one-way skid distance, ft.,
Load = weight of the trees, lb.,
Ratio = machine weight/1,000/horsepower, and
No. Bunches = number of bunches per cycle.

This equation contains one stand variable, skid distance; one machine variable, ratio, that considers both machine weight and horsepower; and two load variables, load size and the number of bunches.

The effect of each of these four variables on time per cycle and productivity was calculated using the above model and the averages for each of the four variables. The averages were: skid distance, 650 feet; load size, 3,200 pounds; ratio, 0.18 (180 pounds/Hp); and number of bunches, 1.15. For the purpose of illustration, three variables were held constant and only one was changed. In actuality, load was significantly correlated with ratio and the number of bunches, and an independent comparison of these variables is not statistically correct.

Skid distance over the observed range affected time per cycle more than the other variables (Figure 2). Estimated cycle times ranged from 2.89 minutes at a 200-foot skid distance to 5.68 minutes at a 1,200-foot skid distance. For each 100 feet of additional skid distance, cycle time increased 0.28 minute. As cycle time increased, productivity decreased. The effect is not linear because the load in cords is multiplied by the reciprocal of cycle time. On the average, 75 percent of the cycle time was spent traveling, so skid distance would be expected to have a significant effect. In fact, skid distance alone accounted for 67 percent of the variability in the data.

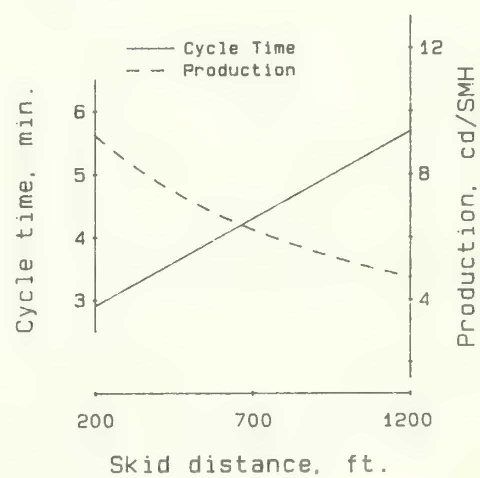


Figure 2.--Time per cycle in minutes and production per scheduled machine hour (SMH) as a function of skid distance.

Load weight can affect time per cycle by slowing the loaded travel speed of the skidder and by increasing the delimbing time (Figure 3).

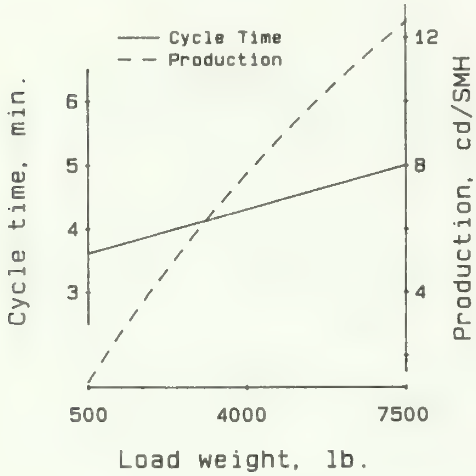


Figure 3.--Time per cycle in minutes and production per scheduled machine hour (SMH) as a function of load weight.

Cycle time increased 0.02 minute per 100 pounds of load weight. The relationship between load weight and production is almost linear because the increase in time is so small. Production increased by about 880 pounds, or 0.16 cord per 100-pound increase in load weight. This figure demonstrates that load weight is the most important variable affecting skidder productivity.

The number of bunches skidded increased the grappling time because of the additional movement - opening and closing the grapple and positioning the load (Figure 4). Since load

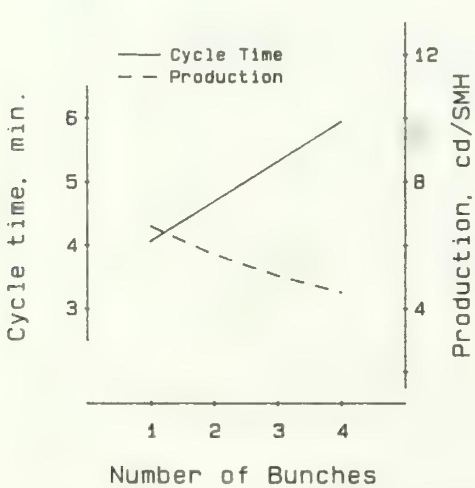


Figure 4.--Time per cycle in minutes and production per scheduled machine hour (SMH) as a function of number of bunches grappled.

size is the most important variable affecting productivity, the skidder should transport the maximum load each cycle. Since the feller-buncher can create any size bunch, picking up multiple bunches does not necessarily mean increasing load size. For this study, the time penalty associated with acquiring additional bunches for a full load versus picking up a full load from one bunch was more important. Picking up an additional bunch required 0.63 minute. (Building large bunches can decrease feller-buncher productivity, so the machine limiting production or having the highest cost per unit of production should be favored when determining the method of operation.)

To optimize skidder productivity, the correct size bunch should be built. Normally, a skidder operator will only grapple one bunch because two bunches would be too large a load. During this study, only one bunch was skidded per cycle 86 percent of the time, and two bunches were skidded 13 percent of the time. Three and four bunches were picked up only once each; so, the linear effect for three and four bunches is probably not accurate.

Ratio, representing the effect of the machine, also affects time per cycle and production (Figure 5). The effect is not pronounced

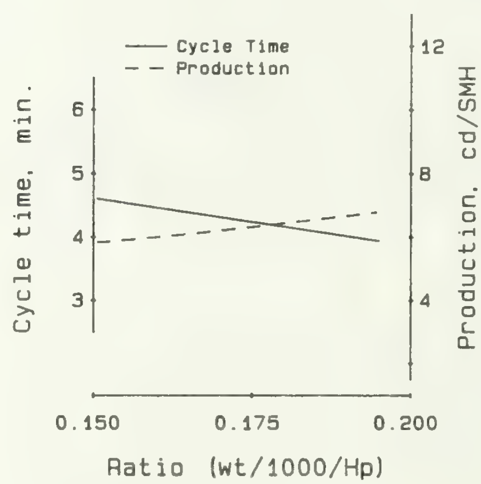


Figure 5.--Time per cycle in minutes and production per scheduled machine hour (SMH) as a function of ratio.

and it is the opposite of what would be expected. As the ratio increased, time per cycle decreased, indicating that underpowered machines are more productive. This may be true when the machines are underutilized; maximum loads are never skidded. The smaller skidders have higher machine weight to horsepower ratios but are more maneuverable and cycle time may be reduced because of the maneuverability.

Figure 6 depicts the load size for each type machine in study by horsepower. The vertical line

represents the range in load sizes for each machine. The short horizontal line intersecting the vertical line represents the average load size for that machine. As the figure indicates, load size decreased slightly as machine horsepower increased. This represents a significant underutilization of the larger machines. It was not possible to determine the reason from the data available. One possible explanation is the physical size of the gate. Large loads may be too wide to effectively delimb using a gate. If this is the case, larger machines are not cost effective.

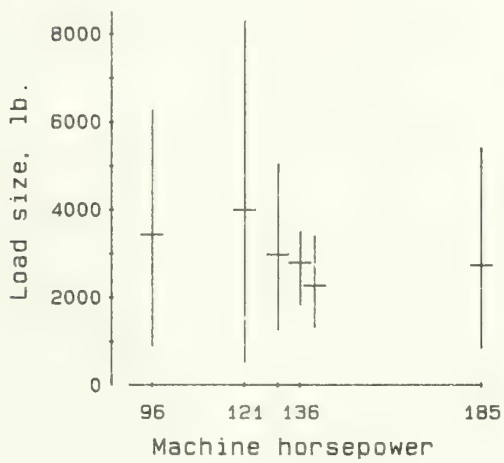


Figure 6.--The range in load size (vertical line and average load (short horizontal line) for eac machine type by horsepower (since two machines have 136 horsepower, one was moved slightly to the right).

Although load size does not increase with machine size, it was postulated that the larger machines would travel faster with the same size load. This was not the case as shown in Figure 7. The plot displays the range and average Again, the larger machines do not show an improvement over the smaller machines. If the machines are under utilized, travel speed may be more a function of operator comfort and trail conditions than of machine size.

Because the larger skidders were not more productive than the smaller ones, the cost per cord was calculated to identify the penalty associated with underutilizing a larger machine. The model was used to calculate productivity based on a skid distance of 650 feet and the range in load sizes depicted in Figure 6.

Machine rates are calculated in Table 3. The machine rates were divided by productivity based on load size to produce Figure 8, a graph of cost per cord as a function of load size.

Only the largest and smallest machines are depicted in Figure 8. The Timberjack 520,

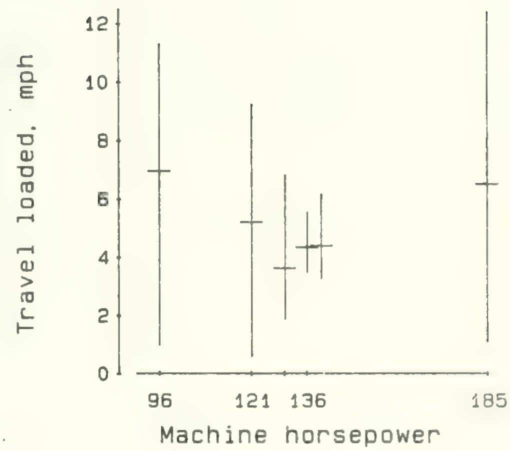


Figure 7.--The range in travel-loaded speed (vertical line) and average travel-loaded speed (short horizontal line) for each machine type by horsepower (since two machines have 136 horsepower, one was moved slightly to the right).

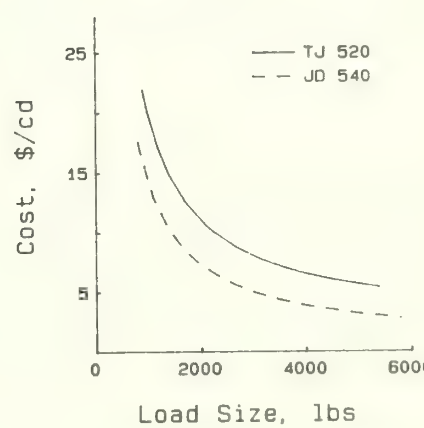


Figure 8.--Cost per cord as a function of load size for the Timberjack 520 (TJ 520) and John Deere 540B (JD540).

because it is a larger, more expensive machine and was no more productive than the smaller machines during this study, had the highest cost per cord. The John Deere 540B was the smallest skidder in the study and produced the lowest cost per cord curve. More than the difference between the machines, Figure 8 demonstrates the importance of load size. As load size decreases, costs increase at a faster rate. This same relationship was illustrated in Figure 3.

Table 3.--Machine rate calculations (Miyata 1980) for the Timberjack 520 (TJ520), Tree Farmer C7D (TFC7D), Timberjack 380 (TJ380), Caterpillar 518 (C518), Franklin 170 (FK170), and John Deere 540B (JD540).

| | TJ520 | TFC7D | TJ380 | C518 | FK170 | JD540 |
|---|---|---|---|---|---|---|
| List Price | $130,923 | $86,865 | $88,814 | $101,838 | $81,100 | $82,000 |
| Average Annual Investment | 89,028 | 59,068 | 60,394 | 69,250 | 55,148 | 55,760 |
| Depreciation | 13.97 | 9.27 | 9.47 | 10.86 | 8.65 | 8.75 |
| Interest, Insurance and Taxes | 10.68 | 7.09 | 7.25 | 8.31 | 6.62 | 6.69 |
| Labor | 9.10 | 9.10 | 9.10 | 9.10 | 9.10 | 9.10 |
| Fuel | 5.18 | 3.81 | 3.81 | 3.64 | 3.39 | 2.69 |
| Lubrication | 1.55 | 1.14 | 1.14 | 1.09 | 1.02 | 0.81 |
| Maintenance and Repair | 11.17 | 7.41 | 7.58 | 8.69 | 6.92 | 7.00 |
| Machine Rate | 47.18 | 34.73 | 35.22 | 38.34 | 32.86 | 32.41 |
| | ===== | ===== | ===== | ===== | ===== | ===== |

## CONCLUSION

Planning timber harvesting operations to maximize profit requires a recognition of the factors that affect the operation. Load size is the most important variable affecting skidder productivity and skid distance is the most important variable affecting time per cycle. The correct bunch size should be built so the skidder is required to grapple only one bunch per cycle. Also, the timber harvester should recognize the limitations imposed by the system and not purchase equipment that is not cost effective.

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## Interactions and Influences

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University of Florida

# HYDROLOGIC EFFECTS OF FLATWOODS SILVICULTURE[1]

Hans Riekerk[2]

Abstract. -- Old-field slash pine flatwoods forest was harvested and regenerated with high and low levels of disturbance and compared against a control. All water table levels increased, but only the high disturbance treatment generated significantly more runoff. Annual water balances were calculated using evapotranspiration data from a weighing lysimeter.

## INTRODUCTION

The hydrology of pine flatwoods in the coastal zone is mostly controlled by the poorly-drained condition of rather level soils often underlain by some impermeable layer. The high infiltration rate of these forest soils minimizes runoff until the water table comes near the surface and saturates the soil. Then surface runoff from seasonally high rainfall rapidly reaches the drainages and swamps resulting in a high ratio of stormflow to rainfall or R-index (Hewlett and Hibbert; 1967). Drainage improvement decreases the resistance to runoff and increases soil moisture storage capacity, and may generate more stormflow and baseflow at the cost of intermediate flow rates (Heath, 1978). Improved drainage deepens the aerated soil zone, but may cause droughty conditions in sandy hammocks. Some lateral recharge occurs from interspersed ponds to the water table of pine flatwoods during the dry seasons (Heimberg, 1984), but deep seepage to the groundwater aquifer is limited (Conover et al., 1984).

Stormflow is the quickflowing portion of runoff that exceeds baseflow. It derives from the direct precipitation on and increased discharge from the saturated soil expanding and contracting in extent during a storm event (Hewlett and Hibbert, 1967). Stormflow expressed as percent of rainfall is an index of the flashiness of runoff from landscapes. Stormflow is cumulative downstream in contrast to peakflow which becomes attenuated. Stormflow data is mostly used for engineering designs of channels, culverts, and dam stuctures.

Evapotranspiration asserts priority demands on soil water and has potential for the manipulation of runoff water balances (Lull, 1964; Ponce, 1983). Transpiration is proportional to forest leaf area and rooting depth, while canopy interception of rainfall is related to leaf area, stand density and deciduousness. Evaporation from ground surfaces is less in the forest than in the open because of more shading and less air flow.

## LITERATURE REVIEW

The above generalities have been discussed but precious little information has been published for poorly-drained landscapes. One project assessed the hydrologic and water quality patterns of triplicate small flatwoods watersheds in southeastern Arkansas (Beasley and Granillo, 1985). Clearcut harvesting increased water yields and peakflows significantly for the first year. Selection cutting did not show a difference between annual water yields based on the standard deviation of replicates. However, when pre-treatment annual water yield ratios are used in the analysis of post-treatment data, to account for the initial differences between watersheds, cutting effects become apparent.

Runoff in poorly-drained pine flatwoods is mostly controlled by rainfall and degree of surface soil saturation as indicated by the water table level. This has been tested for flatwoods in south Florida showing a reasonable correlation (Konyha et al., 1982).

The rainfall and water table depth above mean sea level were used to predict peakflow from a forested coastal watershed (Williams, 1979). The resulting equation appeared to support the theory of variable source areas for runoff (Hewlett and Hibbert, 1967) in that stormflow is initiated when the watertable reaches the bottom of drainages and then increases proportional to the expanding area of the saturated soil. Partial cutting in other but similar sites caused water table rises averaging 1.1 ft (Williams and Lipscomb, 1981). Responses to most harvesting treatments persisted for another year, but became in part amplified by the drought period when water tables of the fully forested controls were farther drawn down by evapotranspiration.

Data from another but very poorly-drained coastal watershed showed a very similar peakflow equation (Rodriguez, 1981). However, during the first year of clearcut harvesting and regeneration not much more runoff was generated, which supports the above observation that the response of water table levels to tree removal is proportional to the water table depth (Langdon and Trousdell, 1978; Williams and Lipscomb, 1981). This proportionality has only been correlated with the water supply for and demand by the remaining vegetation, but may also be explained in part by the drainable porosity (Williams, 1978) which reduces with depth.

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[1]Paper presented at the Southern Silvicultural Research Conference, Atlanta, GA, Nov. 4-6, 1986.

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Optimum water table depth for tree growth was in the lower rooting zone (White and Pritchett, 1970) and was strongly affected by micro-relief (Lorio and Hodges, 1971). A highly fluctuating water table created periodic anoxic soil or drought conditions reducing annual tree growth. Cypress pond drainage decreased average water levels but increased the seasonal fluctuations (Vickers, 1980), suggesting a possible negative effect on tree regeneration and growth.

Irrigation of an isolated cypress pond with waste water showed some overflow to occur during the late summer and winter seasons, but most water slowly percolated into the surrounding soils (Heimburg, 1984). Evapotranspiration as measured from daily waterlevel fluctuations was found to be controlled mainly by the deciduous canopy, averaging about 0.16 inch/day during the growing season.

Stormflow runoff as a proportion of its rainfall (R-index) has been proposed to describe the major storms contributing to downstream flooding (Hewlett and Hibbert, 1967). Mapping of such data for the Georgia coastal plain showed the poorly-drained pine flatwoods to yield more than 16% of rainfall in stormflow, while the inland deep sands showed stormflow to be less than 4% of rainfall (Woodruff and Hewlett, 1971). Stormflow data from the above very poorly-drained coastal watersheds showed the response to be 26% regardless of forest treatment (Rodriguez, 1981).

Evapotranspiration has not been measured for the coastal pine flatwoods forests. Transpiration was measured using plastic airflow chambers and used in a simulation model resulting in about 40 inch/year, excluding interception (Golkin, 1981). Interception ranges from 4-40 pct of annual rainfall depending on tree density (Burger, 1979; Riekerk and Korhnak, 1984). Evapotranspiration of cypress swamps was estimated from water fluctuations at 33 inch/year (Heimberg, 1984), but transpiration was measured at about 50 inch/year (Brown, 1981).

## METHODS

An ongoing cooperative and integrated study of ecological and environmental consequences of pine flatwoods intensive forest management practices was initiated during 1976. The study site was 25 miles northeast of Gainesville, FL, in the large Bradford Forest of a cooperating industrial timber company. The climate is characterized by 55 inches of evenly distributed rainfall with some dry periods in the spring and fall seasons (Dohrenwend, 1978; Jordan, 1984). Mean temperature is 70 F, averaging 57 F in the winter and 81 F in the summer. Droughts occur every 4 years with severe conditions every 7 years. Pan evaporation is 66 inches/year.

The area was in old-field pine flatwoods forest, containing 20-40% cypress ponds, and interspersed agricultural lands. The dominant canopy trees were slash pine (Pinus elliottii Engelm.) with scattered longleaf pine (P. palustris Mill.) on the better drained flatwoods sites, and bald cypress (Taxodium distichum (L.) Rich.) mixed with sweetbay (Magnolia virginiana L.), sweetgum (Liquidambar styraciflua L.) and red maple (Acer rubrum L.) in the ponds. Understory shrubs were dominated by sawpalmetto (Serenoa repens (Bartr.) Small), gallberry (Ilex glabra (L.) Gray) and fetterbush (Lyonia lucida (Lam.) K Koch).

The soils are the Stilson series (Arenic Plinthic Paleudult) in flatwoods and Mascotte and Surrency series (Ultic Haplaquod) in ponds. The sandy soils are underlain by a slowly permeable clay layer (Ks = 0.03-0.3 inch/day) about 8 ft thick with sandy gaps leading into the Hawthorn Formation of sand, clay and limestone layers (Pratt, 1978). The Ocala Group below this formation is the main water supply aquifer for the region.

Three watersheds (WS1= 165 acres, WS2= 120 acres, WS3= 346 acres) were isolated by road-dikes with interior ditches leading to longthroated recording flumes (Replogle et al., 1978). About 40% of WS1, 24% of WS2, and 47% of WS3 were in cypress ponds. All pond and water table wells had recorders, and a raingauge network supplemented the central weather station. Soil moisture was measured with a neutron probe at 6 and 18 inch depths adjacent to selected recording wells. Depth of rust on steel rods at the same sites was measured seasonally (McKee, 1978).

Daily evapotranspiration was measured with a 10-ton weighing lysimeter within a pine plantation at the Austin Cary Forest near Gainesville (Riekerk, 1982). A nearby weather station provided data to relate potential to actual evapotranspiration for use at the Bradford Forest.

After a year of pre-treatment calibration 49 pct of WS1 was harvested and regenerated with minimum disturbance, which included shortwood harvesting, chopping, bedding and planting. About 74 percent of WS2 was machine harvested, and burned, windrowed, harrowed, bedded and planted. The 40-year old-field forest of WS3 was left undisturbed as a reference.

Hydrologic analyses followed standard procedures developed for paired watershed data (Swindel and Douglass, 1984; Hewlett and Doss, 1884). The change between pre-treatment and post-treatment regression slopes was calculated for each year and tested for significance.

## RESULTS AND DISCUSSION

### Water tables

The water table data have been plotted in Figure 1 and show a significant rise in the two treatment watersheds after harvesting in November 1978. The effect was greater when the water tables were down, and diminished only gradually. The pre-treatment calibration data had a high correlation coefficient of 0.94, but the treatments increased variability of infiltration and water table recharge, and which became compounded by a slow rewetting of airpockets created deep in the soil by the drought. The first year data show less of a response under the maximum disturbance treatment which is possibly due to less infiltration into the machine compacted soil. The water tables after treatment remained higher than in the control. However, the control forest could have lowered the water table because of continuing stand development and increased water use.

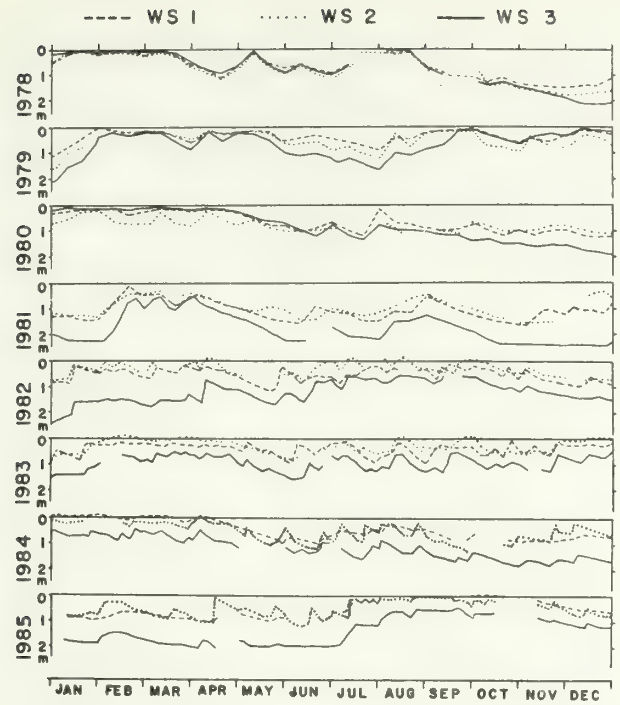


Figure 1. Weekly water table fluctuations.

Soil moisture had some relationship to the depth of the water table. Examination of scattergrams showed soil moisture at 0.5 ft depth to decrease from 20 to 8 percent (by weight) with the water table dropping to 2.5 ft, but any further drop did not change the moisture content very much. The soil moisture at 1.5 ft depth showed no correlation with the water table level unless it fell below 2.5 ft causing moisture to decrease 3.3 percent per ft of drop down to 4 ft depth. These data suggest that the moisture content of the sandy soil is related to water table depth only when within a few feet.

The unsaturated zone has an oxidizing atmosphere which can be used to indicate mean seasonal water table depth. Depth of rusting (R ft) of steel rods adjacent to some recording wells was predicted by $R = 0.37 + 0.36\ WT$ (CV = 0.48 and SD = 0.3 ft). The fluctuating water table in the sandy soil averaged 2.3 ft depth with a large variability of oxidizing conditions during the seasonal observation periods. The data published for heavier organic-rich coastal zone soils with very shallow water tables (average depth 0.6 ft) showed a nearly one-to-one fit and much better correlation (McKee, 1978).

Runoff

Removal of the trees reduces evapotranspiration resulting in more water available for groundwater recharge and runoff. The magnitude of response is proportional to forest canopy reduction and solar radiation load (Hibbert, 1967). The totals from Table 1 show an increase of first-year yields of 1 and 6 inch for the watersheds treated with minimum and maximum disturbance silviculture, respectively. However, the water yield increase from the maximum

Table 1. Actual and predicted annual runoff.

| Year | Rain fall | Con-trol | Min disturb Act | Pred | Diff | Max disturb Act | Pred | Diff |
|---|---|---|---|---|---|---|---|---|
| | inch/year | | | | | | | |
| 1978 | 57 | 22 | 24 | - | - | 15 | - | - |
| 1979 | 54 | 4 | 6 | 5 | 1 | 10 | 4 | 6*** |
| 1980 | 46 | 14 | 5 | 15 | -10*** | 3 | 15 | -12*** |
| 1981 | 36 | 0 | 0 | 0 | 0 | 1 | 0 | 1* |
| 1982 | 57 | 8 | 4 | 8 | -4*** | 3 | 8 | -5** |
| 1983 | 65 | 18 | 14 | 21 | -7*** | 26 | 23 | 3 |
| 1984 | 45 | 8 | 9 | 8 | 1 | 12 | 8 | 4** |
| 1985 | 51 | 7 | 3 | 8 | -5*** | 13 | 8 | 5** |

* < 5 pct probability
** < 1 pct probability
*** < 0.1 pct probability

disturbance treatment was only significant. These yield increases fitted well with the responses of other watersheds in the eastern United States. Calculations with an equation based on degree of canopy removal and solar radiation (Douglass and Swank, 1975) resulted in 4 and 7 inch for the two treatments, respectively. Annual water yields for the post-treatment years continued to show more runoff from the highly disturbed watershed during normally wet years, as could be expected from the water table data, but the low disturbance watershed showed less runoff than predicted and expected from the water table levels. It is quite possible that both calibrations with the control watershed have shifted downward in response to forest maturation.

Stormflow runoff before and after the treatments only showed a treatment effect of midsized storms on the maximum disturbance watershed (Swindel et al., 1983) partly because large storms were absent. The effect was probably due to complete vegetation removal, orientation of the windrows toward the drainage channel, and subsoil compaction by heavy machinery. Water table rises of about one inch have been measured when machinery passed nearby with the table 2-3 feet down (unpublished data, Riekerk).

Water balances

The data showed that evapotranspiration regulates the amount of water available for runoff and water table recharge. Evaluating evapotranspiration from the water balances of the leaky watersheds in the study area is difficult, but can be obtained from a lysimeter. The actual/potential evapotranspiration ratios from the lysimeter were applied to weather station data from the Bradford Forest. Calculated evapotranspiration was used in the water balances of the three watersheds (Figure 2). Residual values of the annual water balances represent seepage plus changes in storage, and contain all the measurement errors. The average seepage value of 1.4 inch/year was very similar to that calculated by darcian flow through the underlying clay layer (Conover et al., 1984; Pratt, 1979). However, similar measurements for two small 10-acre watersheds in the same forest resulted in average seepage values of 13 inch/year (Riekerk and Korhnak, 1984). This may be due to less runoff from the small watersheds without any ponds, and/or more gaps in the underlying clay.

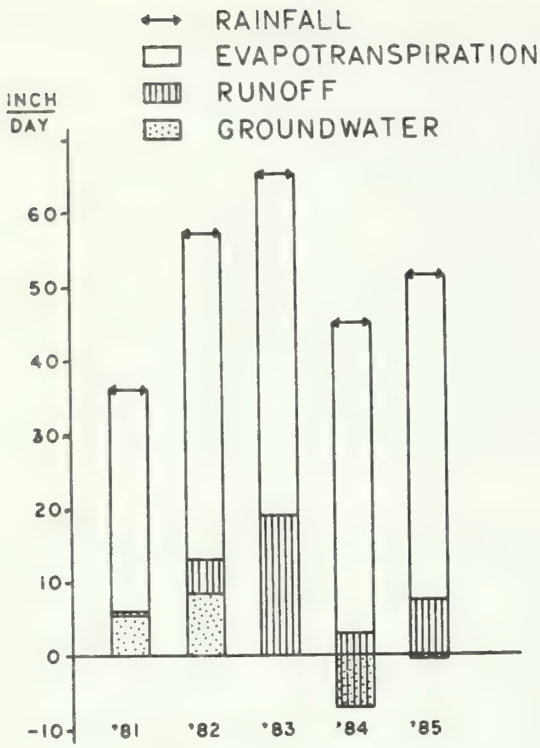


Figure 2. Water balances of the Bradford Forest.

## CONCLUSIONS

Flatwoods pine forest harvesting and regeneration increased water tables, runoff yield, and stormflow proportional to the degree of disturbance.

The effects on water tables were more evident at deeper depths because of lower soil porosity. This created seasonal differences due to dry periods.

Runoff water yield was increased by the maximum disturbance treatment during wet years, but the minimum disturbance treatment apparently reduced annual runoff as compared to the control.

The stormflow of intermediate storms was increased possibly due to the orientation of windrows toward the drainage channel, and to subsoil compaction.

A severe drought year during the study period showed a very slow recovery of hydrologic behavior. It required a whole and very wet year to recharge the system and bring runoff back to normal levels.

Annual water balances that included calculated evapotranspiration showed little deep seepage in the large watersheds but ten times more from small watersheds without cypress ponds.

## ACKNOWLEDGEMENTS

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# STRIP CUTTING TO REGENERATE EROSION-CONTROL PLANTATIONS OF LOBLOLLY PINE[1/]

S. J. Ursic and P. D. Duffy[2/]

Abstract.--A serious problem in the Coastal Plain is adequate regeneration of loblolly pine after harvest. The problem is especially acute where the pine was established to control erosion. Such plantations, largely on small private holdings, are now being harvested. Large acreages are reverting to hardwoods, and the sites are not sufficiently improved for adequate growth of most desirable hardwood species. Four small catchments of loblolly pine in west Tennessee were strip-cut with natural pine regeneration. Adequate pine reproduction and only slight, short-lived impairment of water quality demonstrated strip cutting as a practical solution.

## INTRODUCTION

Public Law 92-500 was passed in 1972. Its goals were to maintain and improve the quality of the Nation's waters. It also directed the States to develop water-quality standards. Information on the quality of water flowing from relatively undisturbed forest lands was meager, and such information was needed to assess changes due to forestry practices as well as to develop reasonable control strategies. These needs prompted new research on forested catchments in a number of Southern States.

Coincident with these needs was deep concern over the loss of substantial acreages of pine to upland hardwoods, especially on nonindustrial private forests. Such forests now occupy two-thirds of the commercial forest land in both the Midsouth and Southeast.

Over the last 10 years, 950,000 acres of nonindustrial private forests in the Southeastern States were harvested, either by clearcutting or high-grading, and kept in timber. Of these 950,000 acres, 610,000 acres supported pine or oak-pine stands when harvested, and only 54 percent of the 610,000 acres were successfully regenerated to pine or oak-pine (Knight 1985).

In the Midsouth, nonindustrial private owners now hold 78 percent of the upland hardwood acreage, including an increase of 458,000 acres from 1977 to 1985. The increase coincides with a decline in natural pine and oak-pine and is at least partially due to the selective harvest of pine and clearcutting without adequate pine regeneration (Birdsey and McWilliams 1986). In addition, about 7 million acres of pine plantation are held by nonindustrial private owners in the South and Southeast, a large portion of which were established on eroded and abandoned farmland.

In terms of area, harvesting is the most important forestry activity. As such, it is of primary interest to foresters and others concerned with both hydrologic changes, including water quality, and forest trends. During 1974-75, the Forest Hydrology Laboratory installed a study to evaluate the hydrologic effects of harvesting. Harvesting was completed in late 1974, and hydrologic recording was begun in May 1975. Strip cutting with natural regeneration was included to evaluate the potential of this practice for maintaining nonindustrial pine lands in pine.

The loblolly pine (Pinus taeda L.) plantations harvested were established on severely eroded, abandoned farmlands near Lexington in west Tennessee. The plantations on the Tennessee Valley Authority's Pine Tree Branch Watershed (PT) were 29 years old when harvested; those on the nearby Natchez Trace State Forest (NT) were 37 years old. The soils are varying proportions of Lexington silt loam and Ruston sandy loam.

Sixteen small catchments averaging 0.86 acre were instrumented and, in a balanced design with two replications at each of the two locations, the following four treatments were replicated: (1) undisturbed controls; (2) clearfelled and planted

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with pine; (3) clearfelled and planted with pine, with disturbed areas fertilized and sown with rye grass; and (4) strip-cut on contour. Cut strips on the strip-cut catchments averaged about one-chain (66 feet) in width. Leave strips were about one-half chain wide and were left at the top, middle, and bottom contours of each catchment. Some trees in the leave strips were also harvested because of ice damage. The basal area of leave trees averaged about 38 $ft^2$ per acre of watershed at both locations. The number of leave trees per acre of watershed area averaged 91 in the 29-year-old plantations and 44 in the 37-year-old plantations.

Water-quality aspects for the clearcut catchments have been reported (McClurkin and others 1985), and complete hydrologic findings are in preparation. This paper deals primarily with the composition of pine reproduction and associated woody species on the strip-cut catchments.

## METHODS

A regeneration survey of the four strip-cut catchments was made in September 1986, 12 years after harvest. Trees were tallied on 10 milacres on both sides of 10 one-chain transects located at random azimuths and distances from the approximate center of each catchment. Thus, 200 milacres were sampled on each of four areas for a total of 800 milacres or about 25 percent of the total area sampled. Trees on leave and cut strips were tallied separately. The transects selected were approximately proportional to the areas of concentric circles to avoid clustering near the center of the catchment.

Pine reproduction was tallied as seedlings (all stems less than 1.45 inches in diameter at breast height) and by larger 1-inch classes. Hardwoods in the 1-inch diameter class (0.50 to 1.45 inches in diameter breast height) and larger were tallied by 1-inch classes by species. For purposes of some comparisons, pine seedlings 6 feet and over in height were assigned to the 1-inch diameter class. Saplings are trees in the 2-inch diameter class and larger.

## RESULTS

### Natural Regeneration

Twelve years after harvesting, pine regeneration averaged 835 stems per acre, 566 seedlings and 269 sapling size and larger. In addition, there were 126 yellow poplar (Liriodendron tulipifera L.) per acre; 75 of these were sapling size and larger. Thus, regeneration of desirable species averaged 961 stems per acre, of which 344 were saplings and larger (table 1). Almost all the yellow poplar were thrifty single stems of seed origin.

Table 1.--Natural regeneration on strip-cut catchments 12 years after harvest--average of four catchments

| | Stems per acre | | |
|---|---|---|---|
| | Pine | Poplar | Total |
| Seedlings | 566 | 51 | 617 |
| Saplings | 269 | 75 | 344 |
| Total | 835 | 126 | 961 |
| Seedlings (1-inch d.b.h. class) | 171 | 51 | 222 |
| Saplings | 269 | 75 | 344 |
| Total | 440 | 126 | 566 |

Considering only pine seedlings and saplings (835 trees/acre), the area sampled is 100 percent stocked by survey definitions (600 seedlings/acre).

Considering trees in the 1-inch diameter class and larger, there were 440 pine and 126 yellow poplar for a total of 566 desirable stems per acre (table 1). This compares with the average survival of seedlings planted on the eight clearcut catchments, 66 percent or 587 trees per acre at age 6.

Pine regeneration and milacre stocking between locations was inconsistent. One less successful catchment at each location was included with the two having the best results. However, average results for the two locations were quite similar (table 2).

Table 2.--Natural regeneration on strip-cut catchments 12 years after harvest

| | Stems per acre | | |
|---|---|---|---|
| | Pine | Poplar | Total |
| Pine Tree | | | |
| Seedlings | 495 | 55 | 550 |
| Saplings | 215 | 98 | 313 |
| Total | 710 | 153 | 863 |
| Natchez Trace | | | |
| Seedlings | 638 | 48 | 686 |
| Saplings | 322 | 52 | 374 |
| Total | 960 | 100 | 1,060 |

### Stocking

Overall, milacre stocking averaged 44 percent for pine, 10 percent for yellow poplar, and 49 percent of the milacres were stocked with either pine or poplar (table 3).

Table 3.--Stocking of natural regeneration on strip-cut catchments 12 years after harvest

| | Stocking percent | | |
|---|---|---|---|
| | Pine | Poplar | Pine or poplar |
| | Seedlings and saplings | | |
| Pine Tree | 40 | 11 | 46 |
| Natchez Trace | 48 | 9 | 52 |
| Average | 44 | 10 | 49 |
| | Trees 1-inch and larger | | |
| Pine Tree | 26 | 11 | 32 |
| Natchez Trace | 33 | 9 | 38 |
| Average | 29 | 10 | 35 |
| | Saplings | | |
| Pine Tree | 18 | 6 | 23 |
| Natchez Trace | 24 | 5 | 27 |
| Average | 21 | 6 | 25 |

Stocking of either pine or poplar in the 1-inch or larger diameter class averaged 35 percent, and trees of sapling size and larger averaged 25 percent. Thus, milacre stocking was equally divided between seedlings and those of sapling size and larger.

Sixty-two percent of the milacre plots were in the cut-strip areas and 38 percent in the leave areas. As expected, regeneration of pine and poplar in the cut strips was better, but milacre stocking in the leave strips averaged 40 percent, including some advanced regeneration (table 4).

Table 4.--Stocking of natural regeneration on cut and leave strips 12 years after harvest

| | Stocking percent | | | | | |
|---|---|---|---|---|---|---|
| | Pine | | Poplar | | Pine or poplar | |
| | Cut | Leave | Cut | Leave | Cut | Leave |
| Pine Tree | 38 | 40 | 15 | 3 | 48 | 41 |
| Natchez Trace | 56 | 36 | 8 | 10 | 62 | 39 |
| Average | 47 | 38 | 11 | 6 | 55 | 40 |

Regeneration surveys made 3 years after harvest (1977) on two of the four strip-cut catchments indicate that there was not enough seed-in-place to provide adequate pine regeneration (table 5). However, pine regeneration more than tripled, and milacre stocking increased about 2.5 times between 1977 and 1986.

Since the two catchments sampled had the best regeneration in 1986, the average value for all four catchments in the initial sampling was probably less. Thus, even though a survey 3 years after harvesting forecasted poor results or partial failure, the areas were well stocked by 1986.

Table 5.--Natural regeneration of pine 3 and 12 years after harvest on two catchments

| Year | Trees/acre | | | Stocking percent1/ | | |
|---|---|---|---|---|---|---|
| | PT7 | NT8 | Means | PT7 | NT8 | Means |
| 1977 | 130 | 650 | 390 | 10 | 42 | 26 |
| 1986 | 1,260 | 1,375 | 1,318 | 65 | 61 | 63 |

1/Based on 100 milacre plots in 1977; 200 in 1986.

Pine seedlings were distributed among all age classes and ranged up to 15 feet tall, while saplings ranged from 2 to 7 inches in diameter, including some advanced regeneration in the leave strips (table 6). This distribution suggests that regeneration was partially dependent on crown development of the leave trees and an increase of seed production. The results indicate that the leave strips can be narrow--just wide enough for harvesting the leave trees without disturbing the regenerated areas. Periodic observations can determine when to harvest the leave strips. And, if desired, the stands can be improved with very minimum single-tree release.

Table 6.--Distribution of pine regeneration on strip-cut catchments 12 years after harvest

| Seedlings | | Saplings | |
|---|---|---|---|
| Height | Number per acre | Diameter class | Number per acre |
| Feet | | Inches | |
| 0.1-1 | 199 | 2 | 139 |
| 2-5 | 196 | 3 | 62 |
| 6-9 | 118 | 4 | 35 |
| 10+ | 53 | 5+ | 33 |
| Total | 566 | | 269 |

## Hardwoods

Overall, 26 percent of the hardwoods other than yellow poplar were maple (Acer sp.), largely with multiple sprouts. Dogwoods (Cornus florida L.) accounted for 12 percent of the hardwoods, suggesting improvement of the site, and blackjack oak (Quercus marilandica Muench.) 11 percent. No other species comprised more than 6 percent of the hardwoods.

Hardwoods other than poplar averaged 1,614 stems per acre, of which 1,162 or 72 percent were in the 1-inch diameter class (table 7). Another 21 percent were in the 2-inch diameter class. There were 452 sapling hardwoods per acre, compared to 344 pine and yellow poplar saplings.

Table 7.--Hardwoods on strip-cut catchments 12 years after harvest (minus yellow poplar)

| | Stems/acre | Percent in seedlings |
|---|---|---|
| Pine Tree | | |
| Seedlings | 1,330 | 74 |
| Saplings | 480 | |
| Total | 1,810 | |
| Natchez Trace | | |
| Seedlings | 992 | 70 |
| Saplings | 425 | |
| Total | 1,417 | |
| Average | | |
| Seedlings | 1162 | 72 |
| Saplings | 452 | |
| Total | 1,614 | |

Other hardwoods greatly outnumbered pine and poplar in the 1-inch diameter class and were about twice as numerous in the 2-inch class (table 8). However, there were more pine and poplar (169 trees/acre) than other hardwoods (118 trees/acre) in the 3-inch and larger diameter classes.

Table 8.--Pine, yellow poplar, and other hardwoods on strip-cut catchments 12 years after harvest

| Diameter class | Loblolly pine | Yellow poplar | Other hardwoods |
|---|---|---|---|
| Inches | --Number of trees per acre-- | | |
| <1 | 395 | -- | -- |
| 1 | 171 | 51 | 1,161 |
| 2 | 139 | 36 | 335 |
| 3 | 62 | 20 | 94 |
| 4 | 35 | 8 | 19 |
| ≥5 | 33 | 11 | 5 |
| 1-5 | 440 | 126 | 1,614 |

Water Quality

Sediment is the most important constituent affecting water quality in the southern pinery. Sediment concentrations for the strip-cut catchments averaged about 350 mg/l during part of 1975 and 1976 (20 months), but decreased to or below the suggested base rate for undisturbed pine of 60 mg/l during each of the next 5 years and averaged 35 mg/l during this period. Soil export from the strip-cut catchments during the initial 20 months averaged about 300 pounds per acre compared to about 50 pounds per acre from the control catchments. These values contrast sharply with averaged first-year sediment concentrations of 2,700 mg/l and soil loss of 5.9 tons per acre following three methods of mechanical site preparation on similar sites (Beasley 1979).

Average sediment concentrations for the strip-cut catchments were lower than those for the catchments in the two clearcut treatments, but differences were slight and concentrations within treatments varied as much as between treatments, primarily due to characteristics of the gully channels.

Skidding on contour and not disturbing the channels, we feel, contributed to these low concentrations. Restoration of cover on the cut strips should minimize any increases in sediment loss when trees in the leave strips are harvested.

## DISCUSSION

We are aware of one other tested, low-cost alternative to naturally regenerate erosion control plantations that minimized soil disturbance and protected water quality. Van Lear and others (1985) working in the Piedmont obtained adequate loblolly regeneration from seed-in-place after several prescribed burns to control hardwoods before clearfelling. Burning did not significantly affect chemical water quality, and increases in sediment concentrations and sediment export were minimal and short-lived.

Results obtained with strip cutting in this study suggest that seed-in-place on severely eroded areas may be inadequate. Too, burning eroded areas having gully channels in the hilly Coastal Plain has been shown to temporarily impair water quality (Ursic 1986).

Strip cutting may be less satisfactory on better sites due to the potential for increased hardwood competition but appears suitable for regenerating erosion-control plantations after the first rotation and is worthy of further trials. Strip cutting may also be less satisfactory where yellow poplar does not make a contribution. Consideration of these factors can help determine which method to use to perpetuate a pine type.

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# POTENTIAL ALLELOPATHIC INTERACTIONS OF *Sapium sebiferum* ON LOBLOLLY PINE SEED GERMINATION AND SEEDLING GROWTH[1/]

C. A. Gresham[2/]

Abstract.--Allelopathy, the deleterious interaction of two plants via the release of a chemical into the soil or air, has only recently been considered in forestry. There are many examples of reduced seed germination and growth reduction due to phytotoxins for many forest species, but few for loblolly pine. A few published reports indicate that several herbaceous and woody species affect loblolly pine. To confirm an allelopathic interaction one should consistently notice the effect and the presence of the suspected species, eliminate competition for light, water, and nutrients and conduct greenhouse experiments with leachates in artificial potting media and with forest soil. This procedure is being used to investigate the interaction of tallowtree leachates and the germination of loblolly pine seed and seedling growth.

## INTRODUCTION

Allelopathy has been defined as "any direct or indirect harmful effect by one plant (including microorganisms) on another through the production of chemical compounds that escape into the environment" (Rice 1974). The important point in this definition is the production of a compound that is released into the environment. Another interaction between two plants is competition, but allelopathy is not a factor of competition, because a competitive interaction involves the withdrawal of some factor from the environment. The term "interference" has been suggested (Muller 1969 in Rice 1974) to include both allelopathy and competition.

## PRODUCTION AND RELEASE OF ALLELOPATHIC COMPOUNDS

Allelopathic chemicals are most commonly reported to be produced in the leaves, stems and roots of woody and herbaceous species (DeBell 1970, Rice 1974). Leaves are considered to be the most consistent source and roots are found to be sources to a much lesser extent. Rice (1974) reports that flowers and fruits have not been widely assayed for allelopathic chemicals and that the research done on seeds has not revealed many toxins. These results reflect the difficulty of 'teasing out' separate plant parts as the source of the toxin. This same difficulty is present when trying to determine the pathway in which the chemicals enter the environment.

## HOW DO TOXINS ENTER THE ENVIRONMENT?

Four mechanisms are commonly listed for allelopathic chemicals to enter the environment. The first is volatilization, the direct release of the chemical into the air. The chemical can therefore be produced from either the leaves or stems to be released into the air. This mechanism is probably not of importance to southern pine forestry since it is associated with arid regions (Rice 1974).

The most commonly researched mechanism is the rainwater leaching of leaves and stems. Most allelopathic studies involve the application of cold water leachates of leaf and stem material to seeds or seedlings of the test species. DeBell (1971) concluded that this was the mechanism by which salicytic acid entered the soil under cherrybark oak (*Quercus falcata var pagodifolia* Ell.).

Exudation from roots is another mechanism by which toxins can enter the environment. However, this pathway is difficult to isolate from the release of chemicals resulting from root death and the decay of roots by soil microorganisms. Rice (1974) reports that root exudation has been documented for several species.

Many chemicals are released upon the death of plant material and this constitutes another pathway for the release of toxic chemicals. Separating those chemicals released from the death of a plant and chemicals produced by microorganisms is not

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easy, thus the isolation of this pathway is difficult. Also soil microorganisms could convert a non-toxic compound released from plant tissue into a toxic one, thus producing the appearance of the plant tissue releasing the toxic chemical.

As the allelopathic research concerning loblolly pine is discussed, one will notice that more than one of the mechanisms is functioning, as is most probably the case in nature. From a practical standpoint the mechanism responsible for the toxin entering the environment is not what should concern foresters, but rather the effect of the toxins on the germination of crop tree seed and the survival and early growth of desirable seedlings.

## ALLELOPATHY AND SOUTHERN PINE FORESTRY

One of the first papers calling foresters' attention to the potential importance of allelopathy in forest management was DeBell 1970. He reviewed the nature of phytotoxins, the mechanisms by which the toxins enter the environment and environmental effects on phytotoxins. He then summarized examples of phytotoxic activity of woody plants and concluded that the research to date was inadequate to warrant the forest manager considering phytotoxins in the management of forests and forest soils. Ten years later, R. F. Fisher (1980) published a similar review article in the Journal of Forestry in which he discussed allelopathy as a potential cause of pine regeneration failure. In the article he tabulated trees, shrubs and herbs that produce phytotoxins that affect forest trees, and listed the class of the active chemical. He concluded that allelopathy is a selective interaction between certain species under certain conditions, and it should not be blamed for any mysterious regeneration failure. Rather, allelopathy should be considered equally with other possible causes.

A great deal of research has been conducted by botanists and ecologists on allelopathic interactions of tree, shrub and herbaceous species as is evident from the two reviews by E. L. Rice (Rice 1974, 1979). The silviculture and management of loblolly pine has been the focus of untold numbers of studies in the Southeast over the past fifty years (see Wahlenburg 1960 for the "early" literature). Despite these facts there is an amazing lack of research published on allelopathic effects of forest shrubs and herbs on loblolly pine regeneration and early growth. Two explanations are possible. First is that allelopathy is not important in regenerating loblolly pine, and the second is that it is important but has not been given adequate research attention. The following discussion will indicate that there is potential for an allelopathic reduction in germination and early growth, and hence the latter explanation is supported.

## ALLELOPATHY AND LOBLOLLY PINE

One of the first allelopathy studies involving loblolly pine was that of Hollis et al (1982) which screened leachates from nine herbaceous and woody species common to the coastal plain. Leachates from six of the nine species interfered with germination and/or radicle elongation of loblolly and slash pine. They then applied mulches to 6 week old seedlings and noted that the mulch of Eupatorium capillifolium stimulated seedling growth while a mulch of Lyonia lucida decreased growth. They also reported that seedlings planted within 0.5 m of Lyonia lucida debris were smaller than those farther away.

Wheeler and Young (1979) demonstrated that leachates from pots growing Festuca arundinacea reduced the growth of potted loblolly pine seedlings. Likewise, Gilmore (1980) reported that the presence of Setaria faberii seedlings in the same pot reduced the growth of potted loblolly pine seedlings. Also leachates from pots growing Setaria faberii reduced the growth of potted loblolly pine seedlings. In a later study, Gilmore (1985) demonstrated that water extracts of Setaria faberii inhibited the germination and radicle elongation of loblolly pine seed. Cold water extracts of Andropogon virginicus shoots were shown to reduce the stem, root and needle lengths of loblolly pine seedlings (Priester and Pennington 1978).

## PROCEDURE TO IDENTIFY ALLELOPATHIC SPECIES

The previous section indicates that few species have been identified as having an allelopathic relation to loblolly pine, and it is quite possible that others exist. But how does one test or confirm this relation? From the published results and personal experience, I submit that there are three sequential steps that must be taken to identify an allelopathic relation.

First there must be a consistent association between the suspected allelopathic species and reduced seed germination and/or seedling growth. Greenhouse research (Gilmore 1985) has shown that soil texture affects the severity of the allelopathic suppression but the effect is consistently measurable. In the field this step only confirms that a competitive or allelopathic relation exists, but does not differentiate between the two.

Once a consistent association has been established, the competition factors must be eliminated. This involves either observational or manipulative data (greenhouse experiments) to demonstrate that the reduction of germination and/or growth is not due to light availability, water stress or insufficient mineral nutrients.

Finally, greenhouse experiments similar to the ones reviewed above need to be conducted. Standard methods include preparing a cold water extract of leaves and stems of the suspected species, and applying the leachate to seeds in a petri dish and applying the leachate to seedlings growing in an artificial media.

If this pair of experiments indicate a germination retardation or a seedling growth reduc-

tion, then the seedling experiments should be repeated with seedlings growing in forest soil. Tinnin and Kirkpatrick (1985) reported that three broadleaf species reduced root growth of Pseudotsug menziesii and two of these also reduced shoot growth, in an artificial soil mix. However, no consistent expression of allelopathy was observed when field soil was used.

Gilmore (1985) identified eight compounds in leaf leachates of Setaria spp and demonstrated that leaf leachates reduced germination of loblolly pine seed and inhibited radicle elongation. He could not find one of the eight compounds in field soil below a leaf mulch that had been missed periodically. From this, he concluded that Setaria phytotoxins are rapidly converted to nontoxic substance(s) in the soil.

## APPLICATION OF THE PROCEDURE: A CASE STUDY

Three patches of an otherwise homogeneous loblolly pine shelterwood stand in coastal South Carolina do not have the sapling regeneration that is present throughout the stand. But these patches do contain many stems of chinese tallowtree Sapium sebiferum. This observation fulfills the first step of identifying a consistent relation. Since the stand regenerated over 20 years ago, eliminating the competition factors is impossible. Today all that can be said is that the soil and topography of the patches is not different from the rest of the stand, so there are no site differences causing patches of regeneration failure.

Greenhouse experiments have been conducted with cold water leaf leachates of the tallowtree in artificial media and a significant reduction of loblolly pine germination and seedling growth was observed. These experiments are being repeated with soil from the shelterwood stand as a growth media. Thus the final step of confirming an allelopathic interaction is being taken in this study. If the leachates do not reduce germination and growth of loblolly pine, this study will demonstrate the neutralizing effect of a forest soil as in the studies of Gilmore (1985) and Tinnin and Kirkpatrick (1985). If the leachates do reduce germination and seedling growth, this presents a strong case for an allelopathic interaction.

This three step procedure that yields circumstantial evidence without any direct data to indicate an allelopathic relation in the field. One could argue that the leachate solutions are more concentrated than would be found in nature because leaf material was allowed to soak for a period of time, and the forest floor would not flood in a drained forest soil. Any forester with experience in the lower coastal plain, where tallowtree is most commonly found, knows that many areas have groundwater at or above the groundline during the winter. Thus the soaking treatment is not that artificial.

## CONCLUSIONS

Allelopathy can be thought of as chemical warfare among plants and it differs from competition in that a compound is being introduced into the environment, whereas competition is the removal of compounds or energy from the environment. The production of phytotoxins has been long studied by ecologists and botanists, but its role in southern pine forestry has not been widely researched. The few published studies involving loblolly pine indicate that there are several herbaceous and woody species that could reduce the germination of loblolly pine seed and/or reduce seedling growth. Therefore, these species could hinder natural regeneration of loblolly by a seedtree or shelterwood method.

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# EFFECTS OF SILVICULTURAL PRACTICES IN BOTTOMLAND HARDWOODS ON SWAMP RABBIT HABITAT[1/]

G. A. Hurst and M. W. Smith[2/]

Abstract.--Forage and cover for the swamp rabbit were sampled 5 times from August 1980 through August 1981 on 4 mature bottomland hardwood forests (age 55-69 years) in Oktibbeha County, and on a recently clearcut bottomland site in Noxubee County, Mississippi. Three of the forests received improvement cuts 8 to 9 years prior to vegetative sampling. The fourth forest was not cut. Total forage from grasses, sedges, forbs and vines in August was significantly greater ($P < 0.01$) on the clearcut (831 kg/ha) than on the thinned forests (160 kg/ha) and the uncut forest (84 kg/ha). Forage in February was significantly greater ($P < 0.01$) on the clearcut (116 kg/ha) than on the uncut forest (14 kg/ha) and the thinned forest (17 kg/ha) with the highest basal area. The other thinned forests had 32 and 73 kg/ha in February. Vegetative cover (lateral screening cover) was always significantly greater ($P < 0.01$) on the clearcut than on the forests. Thinned forests generally had more cover than the unthinned forest.

## INTRODUCTION

Swamp rabbit (Sylvilagus aquaticus) habitat consists of swamps, marshes, and bottomland hardwood forests (Bruna 1965, Chapman and Feldhamer 1981, Allen 1985). Many bottomland hardwood forests in the South, particularly in the lower Mississippi Valley, have been cleared for intensive agricultural use (Sternitzke 1965, Harris 1984). Since 1937, over 2.67 million ha of bottomland hardwood forest along the Mississippi River have been converted to agricultural use (USDI 1978).

About 8.1 million ha of bottomland hardwood forests remain on river systems in the South (Hodges and Switzer 1979). Garner (1969) and Mullin (1982) stated that silvicultural practices in bottomland hardwood forests improved swamp rabbit habitat. This study was conducted to quantify the effects of certain silvicultural practices on swamp rabbit forage and cover on selected river systems.

## METHODS

Five study areas in the Interior Flatwoods soil resource area (Pettry 1977) of east-central Mississippi were used. Areas 1-4 were mature bottomland hardwood forests in Oktibbeha County, and area 5, located in Noxubee County, was a recently clearcut bottomland hardwood site (Smith 1982).

Area 1 (140 ha) was adjacent to Cypress Creek on Noxubee National Wildlife Refuge (NNWR) and had been cutover in the early 1930's, but had not received any further treatment until 1972-73. At that time, at age 60 years, an improvement cut removed 1/3 of the volume and reduced the basal area from 24 to 16 $m^2$/ha.

Area 2 (89 ha) was also located on NNWR, between Cypress Creek and Oktoc Creek. The forest had been cut-over around 1933 and has not received any silvicultural treatment since purchase by NNWR in 1940.

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Area 3 (10 ha) and area 4 (32 ha) were adjacent, located on Cypress Creek on the John Starr Memorial Forest of Mississippi State University. Both tracts were cut 3 times in the 1960's, and once in 1971. These frequent cuttings maintained basal areas of 13 $m^2$/ha on area 3 and 26 $m^2$/ha on area 4.

Area 5 (40 ha) was adjacent to Sun Creek, about 19 Km west of Macon. Area 5 was a mature bottomland hardwood forest before clearcutting in 1980. All unmerchantable trees were cut and left on the ground, but no further site preparation was performed. Loblolly pine (Pinus taeda) seedlings were hand-planted in December 1980.

Common overstory and understory species in areas 1-4 were red maple (Acer rubrum), common pawpaw (Asimina triloba), American hornbean (Carpinus caroliniana), hickory (Carya spp.), American beech (Fagus grandifolia), green ash (Fraxinus pennsylvanica), sweetgum (Liquidambar styraciflua), blackgum (Nyssa sylvatica), overcup oak (Quercus lyrata), swamp chestnut oak (Q. michauxii), water oak (Q. nigra), cherrybark oak (Q. pagoda), willow oak (Q. phellos), and winged elm (Ulmus alata).

Common groundstory plants included Virginia snakeroot (Aristolochia serpentaria), elephant's foot, (Elephantopus carolinianus), narrow-leaved water willow (Justicia lanceolata), cut-leaved water hoarhound (Lycopus americanus), partridgeberry (Mitchella repens), lizard's tail (Saururus cernuus), giant cane (Arundinaria gigantea), white grass (Leersia virginica), barbed panic-grass (Panicum microcarpon), small-fruited panic-grass (P. polyanthes), spikegrass (Uniola sessiliflora), thicket sedge (Carex abscondita), thin-fruit sedge (C. flaccosperma), woodland sedge (C. hyalinolepsis), bladder sedge (C. intumescens), blunt broom sedge (C. tribuloides), crossvine (Anisostichus capreolata), Boykin clusterpea (Dioclea multiflora), Japanese honeysuckle (Lonicera japonica), Virginia creeper (Parthenocissus quinquefolia), poison ivy (Rhus radicans), and greenbriar (Smilax spp.).

Common plants on the clearcut (area 5) included bush aster (Aster dumosus), fire-weed (Erechtites hieracifolia), horse-weed (Erigeron canadensis), goldenrod (Solidago spp.), broomsedge bluestem (Andropogon virginicus), beaked panic-grass (Panicum anceps), forked panic-grass (P. dichotomum), thicket sedge, bladder sedge, marsh cyperus (Cyperus pseudovegetus), crossvine, Japanese honeysuckle, climbing hempweed (Mikania scandens), and Virginia creeper.

A point-sampling method with a basal area factor of 2.3 $m^2$/ha, was used to estimate stand conditions in areas 3 and 4 in July 1980 and in areas 1 and 2 in May 1981. At each sample point, all prism-recorded trees with a diameter at breast height of 15.2 cm or greater were tallied. Species, diameter, and merchantable pulpwood ($m^3$) or number of 4.88 m logs of sawtimber were recorded for each tree (Table 1).

Permanently marked sampling lines were established in each area. The lines were 100 m apart and perpendicular to creeks. Number and length of lines were a function of area size: Area 1 had 13 lines 342 to 1,187 m long, Area 2 had 4 lines 865 to 946 m in length, Areas 3 and 4 each had 6 lines 201 m long, and area 5 had 4 lines 342 m long.

Vegetative sampling plots were randomly located 20 to 282 m apart along the lines. Forage abundance was sampled by a ranked-set method (Halls and Dell 1966) in August and November 1980, and in February, May, and August 1981. At each sampling plot, 3 circular hoops 107 cm in diameter (0.89 $m^2$) were dropped at arm's length, 1 directly in front of the observer, 1 to the immediate right, and 1 to the immediate left of the observer. Rankings of high, medium, or low were assigned to the hoops according to an occular estimate of the amount of herbaceous forage in each hoop. At the first sample point, the hoop with the high amount of vegetation was sampled. At the second plot, the hoop with the medium amount was sampled, and the hoop with the low amount was sampled at the third plot. High, medium, and low plots were sampled in succession and equal numbers of each were taken. The number of sample plots was determined by Stein's two-stage test (Steel and Torrie 1960.)

Various grasses, sedges, forbs, and vines are the important food plants of swamp rabbits in the South (Richardson 1963, Sullivan 1966, Garner 1969, Smith 1982). Therefore, green, succulent, new-growth parts of those plant groups were hand-picked or clipped to a height of 1.8 m above ground. Rabbits cannot reach this high, but rabbits do cut the entire plant down by clipping at the base so that all of the plant is available. Forage was separated to species, placed in paper bags and dried in a forced-draft oven at 40°C for a minimum of 72 hours and weighed.

A density board (cover board) 15.2 cm wide, 1.83 m tall, and graduated in 30.5 cm intervals was used to rate vegetation considered to be rabbit cover. Cover was rated at the same plots used for sampling forage. At each plot cover rating was made with the board placed 20.1 m from the plot center in each of the 4 cardinal compass points. The observer knelt at plot center, positioned his head 30 cm above ground level, and rated visual obstruction of each graduated interval on the board by living or dead vegetation. A rating of zero was used to designate that none of that interval could be seen (totally obstructed) and 10 designated that all the board interval could be seen. Cover ratings of the 6 intervals were averaged for analysis.

The RUMMACE II Analysis of Variance Program (Scott et al. 1981) was used to analyze rabbit forage abundance and cover. The Least Significant Difference technique (Carmer and Swanson 1971) was used to test for differences among means. All tests were performed at the P = 0.01 level.

## RESULTS

The greatest amount of forage occurred in August, followed by May and November. The least amount occurred in February (Table 2.) Total rabbit forage was most abundant on area 5 (clearcut), significantly so in 4 of 5 samples. Area 1, improvement cut in 1972-73 (8 years prior to sampling forage), consistently had the second highest amount of forage. Area 1 had significantly more total forage in 4 of 5 samples when compared to area 2,

Table 1.--Stand characteristics for 4 bottomland hardwood forests, Oktibbeha County, Mississippi, 1980-81[a].

| Area | Age (years) | Basal area ($m^2$/ha) sawtimber | Basal area ($m^2$/ha) pulpwood | Volume ($m^3$/ha)[b] sawtimber | Volume ($m^3$/ha)[b] pulpwood | No. trees/ha sawtimber | No. trees/ha pulpwood |
|---|---|---|---|---|---|---|---|
| 1 | 69 | 12.9 | 5.5 | 32,031 | 938 | 74 | 677 |
| 2 | 65 | 16.8 | 5.1 | 39,700 | 1,181 | 99 | 427 |
| 3 | 55 | 12.2 | 5.2 | 31,047 | 290 | 74 | 1,207 |
| 4 | 55 | 20.6 | 7.0 | 54,162 | 2,072 | 152 | 384 |

[a]Data includes all stems with dbh of 15.2 cm and greater.
[b]Volume is merchantable amount.

Table 2.--Swamp rabbit forage, oven-dry weight (kg/ha) by plant group, on 4 mature bottomland hardwood forests and a clearcut, Oktibbeha and Noxubee Counties, Mississippi, 1980-81.

| Date | Plant group | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 |
|---|---|---|---|---|---|---|
| Aug. 80 | sedge[a] | 22 A | 7 A | 8 A | 19 A | 134 B |
| | grass | 43 A | 10 A | 6 A | 42 A | 222 B |
| | vine | 109 A | 56 A | 108 A | 89 A | 62 A |
| | forb | 24 A | 10 A | 10 A | 9 A | 274 B |
| | total | 198 A | 85 B | 132 A | 159 A | 691 C |
| Nov. 80 | sedge | 9 A | 4 A | 2 A | 10 A | 59 B |
| | grass | 21 A | 3 A | 4 A | 25 A | 111 B |
| | vine | 48 A | 36 A | 23 A | 9 A | 45 A |
| | forb | 28 A | 2 A | 1 A | 1 A | 35 A |
| | total | 106 A | 44 AB | 29 AB | 44 AB | 250 C |
| Feb. 81 | sedge | 10 A | 2 A | 1 A | 2 A | 39 B |
| | grass | 21 A | 3 A | 4 A | 8 A | 50 A |
| | vine | 41 A | 8 B | 27 AB | 8 B | 19 AB |
| | forb | 1 A | 1 A | 0 A | 1 A | 9 B |
| | total | 73 A | 14 B | 32 AB | 17 B | 116 A |
| May 81 | sedge | 18 A | 5 A | 2 A | 6 A | 248 B |
| | grass | 36 A | 1 A | 1 A | 37 A | 180 B |
| | vine | 102 A | 41 A | 71 A | 45 A | 78 A |
| | forb | 32 A | 4 A | 6 A | 3 A | 154 B |
| | total | 189 A | 51 B | 79 B | 91 B | 660 C |
| Aug. 81 | sedge | 22 A | 12 A | 4 A | 18 A | 36 A |
| | grass | 56 A | 13 A | 31 A | 25 A | 295 B |
| | vine | 138 A | 55 A | 46 A | 92 A | 340 B |
| | forb | 27 A | 3 A | 11 A | 1 A | 300 B |
| | total | 242 A | 82 B | 91 AB | 136 AB | 971 C |

[a]Plant group means in horizontal columns not followed by the same letter differ significantly (P = 0.01).

the area that had not been cut since 1933. Areas 3 and 4 had been cut several times in the 1960's and were last cut in 1971, and generally had more forage than the uncut forest (area 2). Areas 3 and 4 had similar amounts of forage despite different stand conditions.

Total forage on the clearcut increased 41% from August 1980 to August 1981. Forage also increased by 23% on area 1 and by 15% on area 4, but decreased 3% on area 2 and 31% on area 3 in the August samples.

Percent of the total forage in each plant group in the August samples of 1980 and 1981 on forested areas 1-4 was very similar. Areas 1-4 averaged as follows: sedge - 10%, grass - 20%, vine - 60%, and forb - 10%. Plant group averages were different on the clearcut: sedge - 12%, grass - 31%, vine - 22%, and forb - 35%. A marked change occurred in plant group percentages on the clearcut from August 1980 to 1981. Sedges declined from 19% to 4% and forbs declined from 40% to 31%, while vines increased from 9% to 35% of the total forage.

Number of plant species in the forage sample was highest on area 1 (54) in August 1980, but declined to 40 species in August 1981. The other forested areas (2-4), had fewer species, with average numbers of 24 (1980) and 19 (1981). In August the number of plant species increased from 30 (1980) to 35 (1981) on the clearcut.

Area 5 (clearcut) always had significantly more vegetative cover than the forested areas (Table 3). The least amount of cover generally occurred on area 2, which had not been cut since 1933. Area 1, cut in 1972-73, always had the second highest average cover. Vegetative cover was similar on areas 3 and 4.

Low cover ratings were recorded in February on the forested areas, but ratings remained at maximum on the clearcut even in February. Average cover increased slightly on all areas in August 1981 compared to August 1980.

Table 3.--Cover rating (least squares mean in percent) on a density board from ground level to a height of 1.83 m, in 4 mature bottomland hardwood forests and a clearcut, Oktibbeha and Noxubee Counties, Mississippi, 1980-1981.

| Area | Vegetative Cover Rating[a] | | | | |
|---|---|---|---|---|---|
| | Aug. 80 | Nov. 80 | Feb. 81 | May 81 | Aug. 81 |
| 1 | 112 A[b] | 131 A | 129 A | 83 A | 79 A |
| 2 | 184 B | 175 B | 181 BC | 155 B | 144 B |
| 3 | 117 AC | 155 AB | 154 AB | 86 A | 84 A |
| 4 | 153 BC | 174 B | 217 C | 113 A | 115 AB |
| 5 | 5 D | 3 C | 6 D | 0 C | 1 C |

[a]The highest rating possible was 240, which meant there was no vegetative cover.
[b]Means in the same vertical column not followed by the same letter are significantly ($P < 0.01$) different.

## DISCUSSION

A recently clearcut bottomland hardwood tract consistently had the most rabbit forage and vegetative cover. The improvement cut bottomland forest ranked second in forage and cover 8 years after the cut. Two other mature bottomland hardwood forests that had received lighter cuts 9 years prior to sampling rabbit habitat conditions ranked third and fourth in rabbit food and cover. However, differences in forage and cover among the forests were frequently not significant. The bottomland hardwood forest that had not received any silvicultural treatment in about 45 years had the lowest amount of forage and cover.

The relationship of stand conditions to forage was not well delineated. Nonmerchantable stems in the midstory and main canopy probably influenced light penetration (Chambers and Jenkins 1983) and affected rabbit forage and cover.

Basically, any cutting improved rabbit forage and cover. Cover has frequently been mentioned as an important limiting factor for rabbit populations. Improvement or harvest cuts not only permit increased vegetative growth on the forest floor (Garner 1969); they also add cover in the form of tree tops, brush heaps, and stumps, which might be important vegetative structure or cover (Chapman and Feldhamer 1981). Improvement cutting created openings which soon provided dense horizontal cover and increased forage for swamp rabbits.

Terrel (1972) reported the swamp rabbit to be more common in selectively logged bottomland hardwood tracts than mature (uncut) tracts.

The longevity of the effects of selective or final harvest cuts was not determined, but the tracts that had been thinned 8 or 9 years prior to sampling rabbit habitat conditions still exhibited slightly more forage and cover than the tract that had not been thinned. The difference between thinned and unthinned, or degree of thinning, was probably much greater during the first few years after cutting.

A silvicultural system recommended for southern bottomland hardwood forests (Putnam et al. 1960, Johnson 1970) includes clearcutting in small, 4-8 ha blocks to obtain natural regeneration. At age 20-25 years a commercial (pulpwood) improvement cut would be conducted. At about age 40 another commercial (small sawtimber/pulpwood) improvement cut would be performed. Then at age 55-60 another sawtimber thinning would be conducted, followed by a final cut (clearcut) at age 80. According to the findings of this study this silvicultural system would maintain comparatively good swamp rabbit habitat throughout most of the rotation, particularly if the improvement and final cuts were well distributed throughout the bottomland.

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## Poster Session

# NATURALLY REGENERATED LONGLEAF PINE GROWTH AND YIELD RESEARCH

by

John S. Kush, Ralph S. Meldahl, Stephen P. Dwyer, and Robert M. Farrar, Jr.[1/]

The range of longleaf pine (*Pinus palustris* Mill.) extends from southern Virginia to eastern Texas, primarily along the Atlantic and Gulf Coastal Plains with extensions into the Piedmont and Appalachian foothills of northern Alabama and Georgia. It is estimated that virgin longleaf pine forests once covered 30 to 60 million acres of the Southeast. Today that estimate has been reduced to between 5 and 9 million acres (Farrar 1978).

From 1964 to 1967, the U.S. Forest Service established a regional longleaf pine study in the Gulf States. The original objective of the study was to obtain a data base for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine stands. Plots were installed to cover a range of ages, densities, and site qualities.

The study consists of 200+ permanent 1/10- and 1/5-acre measurement plots located in central and southern Alabama, southern Mississippi, southwest Georgia, and northern Florida. Plot selection was based upon a rectangular distribution of 4 age classes ranging from 15 to 100 years, 5 site-index classes ranging from 50 to 90 feet at 50 years, and 5 residual basal area classes ranging from 16 to 165 square feet per acre. A description of plots by age, site index, and basal area is given in Table 1.

Each tree on the net plot (1/10- and 1/5-acre measurement plot) with a dbh > 0.5 inch is numbered, has its dbh recorded to the nearest 1/10-inch, has its azimuth and distance relative to plot center measured, and its crown class determined. A systematic sub-sample of trees from each 1-inch dbh class is permanently selected and measured for height to the live-crown base, total height, and if the tree is dominant or co-dominant, for age from seed. A 1/2-chain isolation strip is maintained around each plot by thinning to the same residual basal area level as the net plot.

The study accounts for change over time by adding a new set of plots in the youngest age class every 10 years. The project is now in its fourth measurement period (20th-year measurement) and the third set of new plots are currently being added.

Using data from the first 5-year growth period, Farrar (1979) developed yield equations and tables to predict current and future stand volumes for thinned natural longleaf pine. The results were later updated with data from the second 5-year growth period (Farrar 1985). Data from the third growth period are currently being analyzed.

Growth and yield predictions for thinned, even-aged natural longleaf pine stands will be updated and expanded with results from the third and fourth 5-year growth periods. In addition, there are plans to develop individual tree and additional whole stand models.

Current and future research will also investigate growth pattern changes over time. Establishing new plots in the youngest age class every 10 years provides a replication over time which will allow the examination of growth patterns over different 10-year periods (1965-75, 1975-85, 1985-95). The genotypes are unknown, but all trees are of the same provenance. If growth patterns change significantly from period to period, the change should be detectable in these data. Then if change is observed, it should be possible to determine if it is abnormal through the use of concomitant data collected on site to account for variation due to climate and soil effects.

The importance of long-term growth and yield studies with time replication is becoming increasingly obvious. If changes in growth patterns are to be identified and possible causes determined, it is imperative that studies such as this one be maintained as others are being established.

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Table 1. Plot Assignments for the Regional Longleaf Growth Study

| Age Classes | Site Index | Residual Basal Areas: Original 30 | 60 | 90 | 120 | 150 | Current 30 | 60 | 90 | 120 | 150 | Projected 30 | 60 | 90 | 120 | 150 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 2 | 1 | | 1 | 1 | | | | | | 3 | 3 | 3 | 3 | 3 |
| | 60 | 2 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 2 | | | 1 | 3 | 2 | 2 |
| 20 | 70 | 2 | 2 | 2 | 2 | 3 | 3 | 5 | 5 | 5 | 5 | | | | | |
| | 80 | 3 | 3 | 4 | 2 | 1 | 3 | 3 | 3 | 3 | 1 | 1 | 2 | 3 | 2 | 4 |
| | 90 | 2 | 3 | 4 | 3 | 3 | | | | | | | | | | |
| | 50 | 1 | 1 | 2 | 2 | | 1 | | | | 1 | | | | | |
| | 60 | 2 | 3 | 2 | 3 | 2 | 1 | 2 | 2 | 1 | 1 | | | | | |
| 40 | 70 | 3 | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | | | | | |
| | 80 | 2 | 4 | 3 | 2 | 4 | 6 | 5 | 5 | 7 | 4 | | | | | |
| | 90 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 2 | 3 | | | | | |
| | 50 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | | | | | | |
| | 60 | 3 | 3 | 1 | 2 | 2 | 2 | 1 | 1 | | 1 | | | | | |
| 60 | 70 | 3 | 4 | 4 | 5 | 2 | 2 | 2 | 1 | 2 | 2 | | | | | |
| | 80 | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 2 | | | | | |
| | 90 | 1 | 1 | 1 | 1 | | 3 | 4 | 5 | 3 | 3 | | | | | |
| | 50 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | | | | | | | |
| | 60 | 1 | 3 | 2 | 2 | | 1 | 1 | | 1 | 2 | | | | | |
| 80 | 70 | 2 | 2 | 4 | 1 | 2 | 3 | 4 | 3 | 2 | 3 | | | | | |
| | 80 | | | 1 | | | 3 | 3 | 3 | 4 | 3 | | | | | |
| | 90 | | | | | | 1 | 2 | 1 | 1 | | | | | | |
| | 50 | | | | | | | 1 | | 1 | | | | | | |
| | 60 | | | | | | 1 | 2 | 2 | 1 | | | | | | |
| 100 | 70 | | | | | | 2 | 3 | 3 | 2 | | | | | | |
| | 80 | | | | | | 1 | | 2 | | 2 | | | | | |
| | 90 | | | | | | | | | | | | | | | |

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# SILVICULTURAL GUIDELINES FOR FOREST STANDS THREATENED BY THE GYPSY MOTH: A SUMMARY[1/]

Kurt W. Gottschalk[2/]

Abstract.--Silvicultural treatments that may minimize gypsy moth impacts on host hardwood stands are recommended based on ecological and silvicultural information on their interactions. Information on utilization of dead trees is provided. While these guidelines have not been tested, they represent the current knowledge of the impacts of gypsy moth defoliation on forest stands.

Silvicultural treatments that may minimize gypsy moth impacts on host hardwood stands are recommended based on ecological and silvicultural information on their interactions. Decision charts are presented that match the proper prescription to existing stand and insect population conditions. Preoutbreak prescriptions focus on reducing stand susceptibility and vulnerability by increasing stand vigor, removing trees most likely to die, reducing gypsy moth habitat, reducing preferred gypsy moth food sources, improving predator and parasite habitats, and regenerating stands that are close to maturity or understocked. Regeneration cuttings before defoliation preserve: seed production, established advanced regeneration, and stump sprouting potential. Outbreak prescriptions prioritize stands for possible insect population control actions and regenerate stands that are close to maturity or understocked. Postoutbreak prescriptions rely on efficient salvage of dead trees and the regeneration of stands that are either understocked due to excessive mortality or are close to maturity. Information on utilization of dead trees is provided. While these guidelines have not been tested, they represent the current knowledge of the impacts of gypsy moth defoliation on forest stands.

## METHODS AND MATERIALS

The use of these guidelines requires a stand examination, analysis of stand and insect characteristics, determination of the proper prescription using decision charts, and implementation of the prescription. The guidelines have been developed based on literature review of pertinent research and incorporation of this information into guidelines.

## RESULTS AND DISCUSSION

Appropriate intermediate stand treatment prescriptions are determined by the proximity of infestation and when defoliation may be expected, coupled with stand characteristics and economic maturity. If the stand is not under immediate threat and defoliation is not expected within the next 5 years, there is adequate lead time in which to take preventive action. Seven silvicultural prescriptions have been described that may aid in reducing timber losses under these conditions. If the stand is poorly stocked (less than C-level; 35 percent) or if the stand is adequately stocked (C-level or better; 35 percent) but is within 5 years of maturity, you may wish to consider <u>stand regeneration</u>. Shortening the stand cycle will allow you to market the current stand, avoid lost value in the sale of dead salvage material, and assure adequate regeneration through seed production and stump spouting from the living trees. If advanced regeneration stocking and stump sprouting potentials are adequate, you can regenerate the stand with a <u>presalvage harvest</u>. For stands where these sources of regeneration are not adequate, then a <u>presalvage shelterwood</u> or <u>sanitation conversion</u> may be considered. If the stand is highly vulnerable or susceptible, then a conversion to nonpreferred species will help prevent the spread and establishment of gypsy moths. On lower quality sites, conversion will usually be to a pine species; higher quality sites can be converted naturally to mixed hardwoods using shelterwood or selection cutting. When stand susceptibility and vulnerability are low, then presalvage shelterwood cutting can develop adequate advanced regeneration but without requiring drastic change in composition.

If the stand is fully stocked but will not reach maturity for another 6 to 15 years, it is advisable to <u>defer cutting for 6 to 15 years, or re-examine</u> for possible protection, early harvest, or salvage need after mortality has occurred. Fully stocked stands that may be 16 or more years from maturity and with less than 80 percent stand density may be handled best by <u>deferred cutting for 10 to 15 years or re-examining</u> status as defoliation becomes an immediate threat. Experience has shown that the stresses created by thinning or cutting remain for 3 to 5 years after treatment. Reduced vigor resulting from this

[1]Poster presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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stress, coupled with gypsy moth-caused defoliation stress, may yield much higher mortality losses. Thus, these higher value, highly stressed stands should be closely observed and possibly sprayed with insecticides if an outbreak is expected during the recovery period. For fully stocked stands that are 16 or more years from maturity and have greater than 80 percent stand density, sanitation thinning or presalvage thinning may be considered, depending upon the percentage of the basal area that is in preferred food species. Sanitation thinning is designed to prevent the spread and establishment of damaging organisms, to reduce stand susceptibility by removing preferred food species and refuges for the gypsy moth, and promote predator and parasite habitat. The treatment is best applied in stands where less than 50 percent of the stand basal area is in preferred food species, and where other management objectives will allow. Presalvage thinning reduces defoliation-caused losses by removing the most vulnerable trees before they are defoliated and killed. The major objective is to reduce stand vulnerability by early removal of those trees that are most likely to die. Presalvage thinning is best suited for those stand conditions described above, but in which more than 50 percent of the basal area is in preferred food species. The most vulnerable trees are poor crown oaks, poor crown other species, and fair crowned trees, particularly on poorer, drier sites. Good crowned trees are least likely to die.

If defoliation is currently taking place or expected within the next 5 years, the most appropriate action is to protect foliage through insecticide application, to closely monitor and evaluate current conditions through stand examinations, or to move ahead with stand regeneration plans as described above. Stand priorities for insecticide application may be based on stand maturity, condition, and value of the stand; the severity of the gypsy moth threat; and planned management objectives. Under certain conditions of low stand value or low risk, the best course of action may be to delay direct treatment and to re-examine the stand after defoliation to assess current condition, extent of damage, and salvage potential.

If defoliation has recently occurred, wait 1 to 3 years to allow resulting mortality to occur. At that time, the stand can be re-evaluated to consider stand regeneration if damage levels are high and current stocking levels are poor, or stand maturity is within 10 years. Salvage harvest can be used when regeneration stocking is adequate. When it is not adequate, then salvage shelterwood or salvage conversion can be used to obtain adequate regeneration or convert the stand to nonpreferred species as in the presalvage prescriptions. If damage levels are low to moderate, current stocking levels are adequate to maintain the stand, and the stand is more than 10 years from maturity, then several intermediate treatments are possible. Salvage thinning is used to salvage dead trees and thin live trees that are present until the stand reaches the proper residual stand density (B-level stocking). If the stocking of live trees is between B- and C-level and there is at least 30 percent mortality, then a salvage cutting is called for. Otherwise, stands with the same stocking levels but less than 30 percent mortality should have deferment of further cutting until they increase in stocking. A more complete description of guides for silvicultural treatment is presented by Gottschalk[3].

Dying trees may be utilized for sawtimber if cut within 1 to 3 years of mortality. Increasing time after death will decrease the stumpage value, the quality of the lumber, and increase drying problems and checks. Veneer trees generally are downgraded to sawtimber status when they die. Trees dead up to 5 years are useable for pulpwood with no loss in quality or yield if bought by weight because the increased volume per ton of the dead trees offsets the increased fines and decay losses.

## CONCLUSIONS

While these guidelines have not been tested, they represent the current knowledge of the impacts of gypsy moth defoliation on forest stands. Opportunities exist to manage forests in areas where the gypsy moth is or will be present in an economical manner without sacrificing management objectives or allowing the insect to dominate management actions as has happened in many areas of Pennsylvania, New York, and other infested areas. Eventually the forest, forest managers, and this exotic insect pest may approach a state of tolerable coexistance.

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[3]Gottschalk, Kurt W. Silvicultural guidelines for forest stands threatened by the gypsy moth. USDA For. Serv. Gen. Tech. Rep. In press.

# INTENSIVE PLANTATION MANAGEMENT EFFECTS ON NUTRIENT POOLS: A CASE STUDY[1]

Charles A. Gresham[2]

Abstract.--Re-establishing loblolly pine plantations with the minimum of site degradation and cost will be of concern to landowners with plantations at or near rotation. Depleting the site's macro-nutrients to the point of decreasing site productivity is one mechanism of site degradation.

Nitrogen and phosphorus pools in the soil, forest floor, and vegetation are being monitored in a 17-year-old loblolly pine plantation in the coastal plain of South Carolina. The monitoring was initiated about one year before harvest and will continue for 3 years after planting. Within the stand, four site preparation methods will be used. Two additional stands of the same age but with different soil types will be added to the study.

## INTRODUCTION

Site quality can be defined as the productive capacity of an area, and is a function of biotic and abiotic factors. Crop species genotype, radiant energy input, soil water content and mineral nutrients are the major growth limiting factors. Forest geneticists are improving the genotype of loblolly and the manipulation of light can be accomplished by competition control and stand thinning. Water manipulation is primarily a matter of draining excess water from the site. However manipulating mineral nutrients, especially the frequently limiting nitrogen and phosphorus, involves the soil and vegetation components. Fertilizers can be added at planting to supplement a deficiency, but this can be expensive and the effect often short-lived. A more biological, and perhaps economical, approach would be to preserve the on-site nutrients as much as possible through the harvest and site preparation operations.

The purpose of this report is to outline a study that is monitoring the nitrogen and phosphorus pools of a rotation-age loblolly pine plantation through re-establishment. Previous research has quantified the nitrogen and phosphorus cycling in older loblolly pine plantations, but little work has focused on the re-establishment phase of the rotation. Re-establishment is the part of the rotation that needs to be studied because during harvest and site preparation, the forest floor and understory vegetation is destroyed, thus decreasing the site's ability to retain nutrients.

## STUDY DESIGN

The study design is randomized complete blocks within three stands. Each of three blocks in each stand will contain four treatment plots and one control plot. Site preparation treatments include:

1. shear, disk and bed,
2. rebed at right angles to original beds, and inject residuals,
3. herbicide before planting, inject residuals, and plant on old beds,
4. same as 3, but with competition control for 1 year after planting,
5. unharvested control.

This design allows testing of the treatment effect for each stand and treatment and block effects for combined stands.

In the field, treatment plots (200' x 200') were installed with 50' buffers, and within each a 65' x 115' measurement plot was staked out. The measurement plot was oriented at right angles to the windrows and included a section of the windrow.

## METHODS

Field methods are divided into pre- and post-harvest. A 100% inventory was made of the trees with species, DBH and total height recorded. Understory vegetation in 10' radius plots and greater than 3 feet tall was clipped at groundline, dried and weighed. Vegetation less than 3 feet tall and the litter layer was sampled in 10-square-foot quadrats. The tree inventory was used to

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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determine the range of trees to be destructively sampled for biomass determination. Thirty pines and twenty hardwoods were felled and weighed in the field.

Initial soil sampling was accomplished by taking a composite sample at two depths (0-6" and 6-12"), in the beds, interbed areas and windrows for all fifteen plots. These samples were analyzed for total nitrogen, ammonium and nitrate, extractable phosphorus, potassium, calcium and magnesium, and organic carbon. Monthly soil samples of the bed areas at both depths are analyzed for ammonium and nitrate.

Rainfall and throughfall are being collected in the open and control areas respectively.

## CURRENT STATUS AND FUTURE WORK

As of November 1986, the preharvest sampling had been completed in one stand and that stand had been harvested. Site preparation is scheduled for July 1987 with planting in January 1988. Each September for three years soil and vegetation samples will be taken. Seedlings and competing vegetation will be clipped and the litter layer removed in 10 square foot plots. The plot will be excavated to remove roots. Soil samples will be taken in the bed, interbed and windrow areas. Rainfall and throughfall collection will continue.

A second stand has been chosen and preharvest sampling will begin immediately. The second stand was as productive as the first, but on a much better drained soil. To complete the study, a third stand will be chosen with the same drainage characteristics as the first, but with a less productive soil.

# Site Preparation

Moderators:

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# COMPETITION IN LOBLOLLY PINE PLANTATIONS FOUR YEARS AFTER REGENERATION USING SEVEN DIFFERENT SITE PREPARATION METHODS [1/]

Ted Needham, J.A. Burger, and C.W. Stafford [2/]

Abstract.--Competition was measured during the fourth growing season in loblolly pine plantations that were established in the Piedmont using seven different site preparation methods. The extent and composition of the competition was assessed and relationships between tree size, various measures of competition, site preparation method, and preharvest vegetational characteristics were examined. The study shows that hardwood competition was not significantly less with increasing site preparation intensity and that the relationship between hardwood competition and tree size was weak. Apparently, other factors play an important role, either in combination with, or in place of competition to limit loblolly pine growth.

## INTRODUCTION

Hardwood and herbaceous competition can be important factors limiting loblolly pine growth in the Piedmont of the southeastern United States. Research begining in the 1950's and extending into the 70's investigated the need for controlling competition following the conversion of hardwood stands and mixed pine-hardwood stands to pine plantations. The results show a significant and consistent increase in growth when pine seedlings were released from over-topping residual competitors compared to no release (Muntz 1951, Shoulders 1955, Miller and Tissue 1956, Hatchell 1964) . Competition from understory vegetation, or that vegetation which predominates after the elimination of the overstory, can also affect the growth of pine seedlings. Current research is directed toward assessing this affect; however, the results have been less conclusive than with overstory competition (Carter et.al 1983, Cain and Mann 1980, Stransky 1980, Bacon 1986). Overall, early control of competition, both understory and particularly overstory, is considered essential for rapid growth and development of loblolly pine.

Survival and early growth of loblolly pine in plantations is enhanced by site preparation (Pehl and Bailey 1983, Lantange 1984, Stafford et al. 1984). This improved performance is often attributed to early and effective control of overstory and understory competition.

The objective of this study was to compare competition levels in four-year-old loblolly pine plantations that were established using seven different site preparation methods, and to relate these levels of competition to tree performance.

## METHODS

A site preparation study was installed on 12 mixed pine-hardwood sites in the South Carolina and Georgia piedmont in 1980 with the seven treatments described in table 1 replicated on each site. The treatments are not all-inclusive of the many available alternatives; however, they represent the spectrum, covering a range of costs, methods (ie. chemical versus mechanical), and intensities of site disturbance.

Competition was measured in late summer of the fourth growing season around 756 randomly selected trees. The trees were located in permanent plots in the treatment areas. Each treatment and site was equally represented. A circular plot whose radius was equal to the height of each sample tree was established and the following competition measurements taken:

[1/] Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanata, Georgia, November 4-6, 1986.

[2/] Graduate Research Assistant, Associate Professor, and Graduate Research Assistant, respectively, Department of Forestry, VPI & SU, Blacksburg, VA 24061.

1) Total height and either ground line diameter (DGL) or the crown dimensions of all hardwood stems by species,
2) the height and crown dimensions of woody shrubs,
3) an occular estimate of percent herbaceous cover, and
4) a 1-5 ranking to reflect the tree's free-to-grow status.

Species specific regression equations were used to convert crown dimensions to ground line basal area (Bacon, 1986). The free-to-grow ranking criteria used were similar to those proposed by the Virginia Division of Forestry (Dierauf and Garner).

The basic measures of competition were used both individually and in the derivation of 1) hardwood basal area per acre, and 2) percent hardwood basal area. Percent hardwood basal area is the proportion of total basal area in each plot consisting of hardwoods.

Competition had been assessed the first and second growing seasons after site preparation using the line transect method. Estimates of the percent cover of various competition components were made (Lantange 1984), and these measures along with preharvest hardwood basal area were used to investigate changes in competition levels over time.

Analysis of variance, regression and scatter diagrams were used to assess the effect of treatment on competition and the effect of competition on tree size.

Table 1. Description of site preparation treatments applied on each of 12 sites in the South Carolina and Georgia piedmont.

| TREATMENT | NUMBER MACHINE PASSESS | PLANTING METHOD | DESCRIPTION |
|---|---|---|---|
| No Preparation | 0 | Hand | No site preparation following harvest. |
| Herbicide Burn | 0 | Hand | Glyphosate in water aerially applied in mid September at 3.9kg/ha ai. Burned 6 weeks later. |
| Chop Burn | 1 | Machine | An empty 3m wide double drum offset chopper behind a D7 tractor. Burned 2-6 weeks later. |
| Shear disc | 1 | Machine | KG blade on D7 sheared and aligned debris while pulling tandem harrow (35" discs) to till the soil. |
| Shear V-blade disc | 2 | Machine | Residual vegetation sheared with a KG shearing blade on first pass. V-blade mounted to D7 created mini windrows while pulling tandem harrow (35" discs) |
| Shear Rake | 2 | Machine | Residual vegetation sheared with KG blade on first pass. Slash raked into windrows on second pass. |
| Shear Rake Disc | 3 | Machine | Residual vegetation sheared with KG blade. Slash raked into windrows. Soil disced with tandem harrow (35" discs). |

RESULTS and DISCUSSION

Treatment Comparisons:

The percent cover of herbaceous, woody shrub, and hardwood competition after 4 years is presented in table 2. Except for the areas receiving no site preparation (33.3% herbaceous cover), herbaceous cover was similar among treatment areas, averaging 64.9%. There were no differences in the amount of hardwood cover among site prepared areas which averaged 20% compared to 35% in the untreated areas. Woody shrub cover was low, 1.4% on the average, and there was no treatment effect. The total percent cover shows that the sites were not fully occupied and competition for resources was only beginning to occur at age 4.

The change in competition cover among treatments from year 2 to year 4 is also presented in table 2. All site-prepared areas exhibited a large increase in herbaceous cover, 33% on the average; however, those that were disced exhibited the largest increase, 10-15% more than non-disced areas. Woody shrub coverage declined in all treatment areas and hardwood cover increased an average of 13.7%. Except for the chop burn and V-blade disc treatment areas which had greater hardwood cover increases on the average, the increases were similar among treatments.

Hardwood basal area results are compared by treatment in table 3. There were no significant differences in hardwood basal area levels among treatments at age 4 with the exception of the untreated areas which averaged 22.6 $ft^2$/acre and the herbicide burn areas which supported an average hardwood basal area of 10.6 $ft.^2$/acre. The very intensive shear rake disc treatment areas supported significantly lower levels averaging 5.2 $ft^2$/acre. In general, all treatments were equally successful in reducing the level of competing hardwood basal area.

Percent hardwood basal area was significantly different between treatments; the disced treatment areas exhibited significantly lower levels than the non-disced treatment areas (Table 3). Percent hardwood basal area is roughly inversely proportional to the average tree volumes in these treatments (Table 4). The smallest volumes are associated with the largest percent hardwood basal area levels; however, whether this is a cause and effect relationship is unknown since the effects of tillage interfere with a direct assessment of competition.

The free-to-grow status of the pines was similar in all areas except the herbicide burn and untreated areas which averaged 2.0 and 3.6, respectively, compared to an average rank of 1.5 for the other treatments (table 3). Even though the herbicide burn rank is greater than the others treatments, it is below the 2.5 rank used to indicate that a release treatment is justified (Todd 1983).

Table 2. Fourth year competition cover by treatment and changes in percent cover from year two.

| Site Preparation Treatment | Herbaceous Year 4 | Herbaceous Change | Woody Shrub Year 4 | Woody Shrub Change | Hardwood Year 4 | Hardwood Change | Total Year 4 | Total Change |
|---|---|---|---|---|---|---|---|---|
| | (Pct. Cover) | | | | | | | |
| No Preparation | 33.3a[1] | -1.9[2] | 0.8a | -6.3 | 35.0b | 11.8 | 72.2a[3] | 1.0 |
| Herbicide-Burn | 61.9b | 22.8 | 1.1a | -10.6 | 23.2ab | 12.7 | 91.7b | 16.5 |
| Chop-Burn | 67.2b | 30.6 | 1.9a | -7.0 | 24.2ab | 18.4 | 102.3b | 35.3 |
| Shear-Disc | 67.6b | 39.3 | 2.0a | -4.7 | 16.7a | 12.9 | 96.5b | 27.3 |
| V-Blade Disc | 64.5b | 36.2 | 1.2a | -4.8 | 22.1ab | 16.9 | 96.0b | 31.3 |
| Shear-Rake | 64.4b | 30.4 | 1.5a | -3.4 | 18.9a | 11.6 | 94.1b | 26.9 |
| Shear-Rake-Disc | 64.2b | 39.6 | 1.1a | -5.0 | 15.1a | 12.0 | 93.5b | 34.3 |
| Average | 64.9 | 28.1 | 1.4 | -6.0 | 22.2 | 13.7 | 92.3 | 24.6 |

[1] Values are means of 12 observations. Each observation is a composite of 9 subsamples. Means within columns followed by the same letter are not significantly different at p <.05 according to Duncan's multiple range test following an acrsine data transformation.
[2] Change= year 4 - year 2.
[3] Total cover includes pines.

Table 3. Treatment comparisons of hardwood competition after four growing seasons.

| Site Preparation Treatment | Hardwood Basal Area ($Ft^2$/acre) | Percent Hardwood Basal Area (Pct) | Free-to-Grow Rank |
|---|---|---|---|
| No Preparation | 22.6c | 85 d | 3.6 |
| Herbicide-Burn | 10.4b | 68 c | 2.0 |
| Chop-Burn | 8.9ab | 59 bc | 1.6 |
| Shear-Disc | 5.9ab | 43 a | 1.4 |
| V-Blade Disc | 6.0ab | 49 ab | 1.4 |
| Shear-Rake | 8.6ab | 59 bc | 1.6 |
| Shear-Rake-Disc | 5.2a | 43 a | 1.3 |

[1] Values are means of 12 observations. Each observation is a composite of 9 subsamples. Means within columns followed by the same letter are not significantly different at p < .05 according to Duncan's multiple range test following an arcsine data transformation for variables expressed as a percent.

Table 4. Treatment comparisons of average tree size after four growing seasons.

| Site Preparation Treatment | Height (ft.) | Ground Line Diameter (in.) | Volume ($D^2H$) ($in^3$) |
|---|---|---|---|
| No Preparation | 6.3 c[1] | 1.26 c | 139 c |
| Herbicide-Burn | 6.6 c | 1.57 b | 202 c |
| Chop-Burn | 6.8 bc | 1.89 a | 293 b |
| Shear-Disc | 7.3 ab | 1.97 a | 328 ab |
| V-Blade | 7.3 ab | 1.93 a | 318 ab |
| Shear-Rake | 7.2 abc | 1.89 a | 285 b |
| Shear-Rake-Disc | 7.5 a | 2.05 a | 380 a |

[1] Values are means of 12 observations. Each observation is a composite of 9 subsamples. Means within columns followed by the same letter are not significantly different at p <.05 according to Duncan's multiple range test.

In summary, the results of treatment comparisons indicate that on the average, control of preharvest competition was achieved resulting in low levels of competition in areas receiving a site preparation treatment. The type and intensity of site preparation created only small differences in the levels of competition by age four. Most of the difference occurred between the herbicide burn and intensive shear rake disc treatments. A competition problem was only beginning to prevail at age 4 as the stands were just beginning to reach full occupancy.

Individual Tree Assessment:

The relationship between tree size and the competition variables was examined both with and without regard to treatment. Overall, no single competition variable explained a large portion of the variation in tree size. Hardwood basal area, percent hardwood basal area, and percent herbaceous cover were the competition variables most associated with tree growth. Other research has also shown them to be the best measures of the competition-tree size relationship (Bacon 1986, Burkhart and Sprinz 1984, Glover 1982). Figure 1 illustrates the relationship of these variables with tree diameter. Diameter of the pines was generally more sensitive to tree size than height or volume index.

Across all treatments, no relationship between diameter and percent herbaceous cover was evident (Figure 1). Within individual treatments, percent herbaceous cover accounted for no more than 3% of the variation in diameter, and this occurred in the chop burn treatment areas. The percent herbaceous cover within each treatment accounted for more variation in tree height than diameter; however, it amounted to no more than 7% of the total and was typically about 2%.

The scatter diagram between pine diameter and hardwood basal area shows only a weak relationship (Figure 1). Visual inspection of the relationship suggests that hardwood competition was not the predominant factor affecting pine diameter until the hardwood basal area exceeded 40 $ft^2$/acre.

Percent hardwood basal area exhibited the strongest relationship with diameter (Figure 1). Overall, the $R^2$ was 0.10. The strength of this relationship was entirely dependent on the small-diameter trees occurring at the highest percent hardwood basal area levels. The pine trees affected by high levels of hardwoods are predominantly located in the untreated areas; however, all treatments had some pines affected by high levels of hardwood competition. All treated areas also had pines affected by the entire range of hardwood basal area.

Multiple regression using hardwood basal area, percent hardwood basal area and percent herbaceous cover provided no additional insight to the effect of competition on growth.

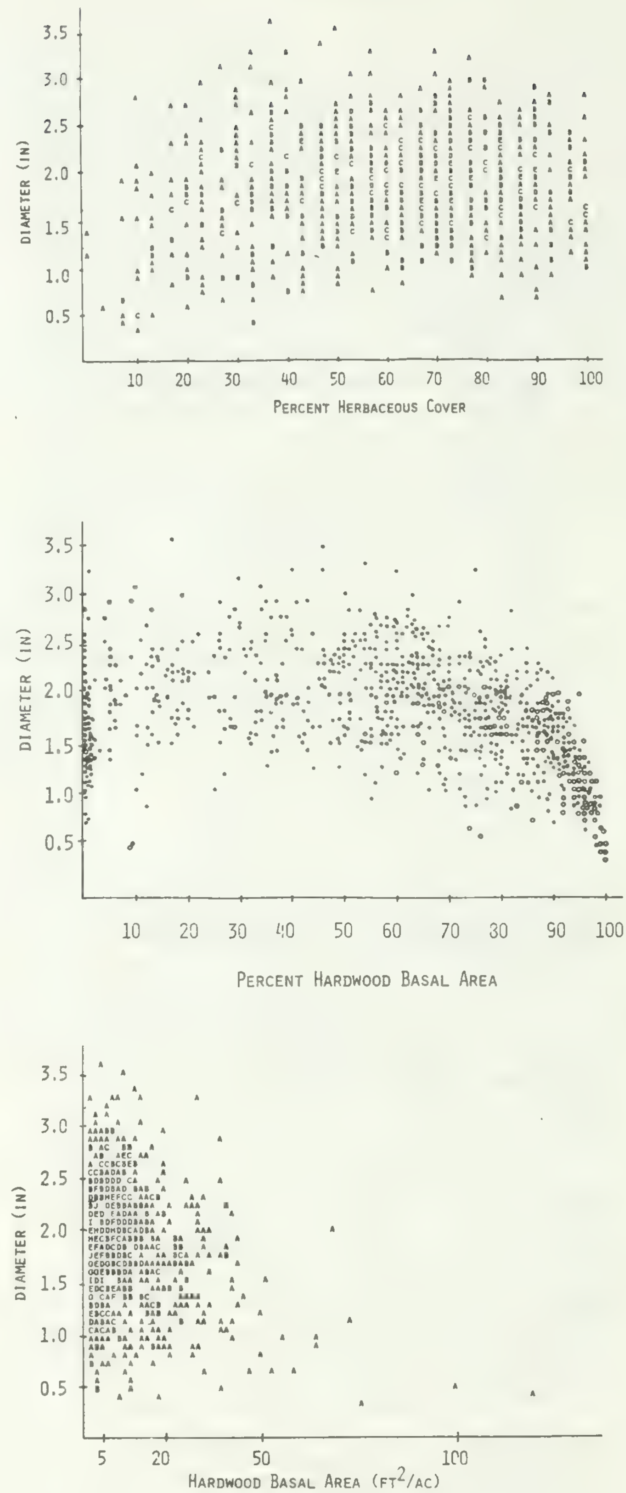


Figure 1. Scatter diagrams of the relationship between tree diameter and various measures of competition.

## CONCLUSION

Although there were significant differences in tree size among the seven site preparation alternatives after 4 growing seasons (Table 6), the evidence to suggest that competing vegetation was the predominant factor affecting tree size is weak. There were few significant differences in competition levels among the various treatments and individual tree assessments showed very weak relationships between tree size and competition. Only at high levels of competition was the relationship strong. Therefore, we conclude that competition alone was not the predominant factor limiting the growth of the pines on the site prepared areas examined in this study. This is not to say that in some instances competition was not the factor most limiting growth or that competition in combination with other factors was not limiting growth. Rather its occurrence as the most limiting factor did not prevail.

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# Soil Density and Harvest Slash Effects on Four-Year-Old Loblolly Pine[1]

J. L. Torbert, T. D. Needham, J. A. Burger[2]

Abstract--Removal of logging slash and forest floor layers in the process of preparing cut-over forest land for pine plantations may reduce site quality and plantation yields. The effects of alternative site treatments on organic residue, soil tilth and loblolly pine growth after four years were compared on eight cut-over forest sites in the South Carolina and Georgia Piedmont. The treatments were: 1) shearing and discing in one pass; 2) shearing, V blading and discing in two passes; 3) shearing and windrowing in two passes; 4) shearing, windrowing and discing in three passes. Residual logging debris remaining on non-windrowed areas was aligned into "mini-windrows" between tree rows with a V blade on the planting tractor. After four years, tree volume index was highest on sheared, windrowed and disced treated areas, but fourth-year height increment was the same among all treatments. Preliminary results suggest that higher levels of harvest slash and litter and lower soil densities on non-windrowed and disced plots could result in superior long-term growth.

## INTRODUCTION

Cutover timberlands in the southern Piedmont are often intensively site prepared by shearing, windrowing and discing to clear residual debris, reduce competition and enhance machine planting. Survival and early growth on sites treated in this fashion are usually improved; however, it is unknown whether the initial growth advantage obtained by this treatment will persist for the duration of the rotation, or if final yields will justify the high cost of this treatment. Stafford and co-workers (1984) reported that shearing, windrowing, and discing resulted in better survival and growth after three years than treatments such as chop and burn, spray and burn, and windrowing without discing. The initial benefits of this three-pass intensive treatment to young established stands includes reduced competition, soil tillage, and increased levels of available nutrients. Despite these regeneration advantages, many foresters are concerned that the initial benefits of such intensive site preparation may be at the expense of long-term productivity.

Shearing and windrowing prepares the cut-over forest site for planting by removing unwanted residual vegetation and harvest slash. Burning the windrows clears the site of debris so that the entire harvested area can be planted. These benefits should be weighed against the concommitant nutrient redistribution and partial depletion that also occurs. Morris and co-workers (1983) found that windrowing on a flatwoods soil resulted in the loss of more than 350 kg N/ha, an amount which was greater than 10% of the total N content of the undisturbed forest ecosystem, or about the same amount that would have been removed in six conventional harvests.

After removal of surface debris, incorporation of the remaining litter layer in the soil surface by discing causes accelerated decomposition and premature release and availability of organicly-combined nutrient reserves. Fox and co-workers (1986) found that 45% of the available N reserves were mineralized during the first year on a cut-over Piedmont site in Virginia that had been sheared, windrowed and disced. The long-term effect of removing such large portions of the nutrient reserves is unclear because no study has documented the balance between nutrient requirement and availability for the duration of a tree crop. Perhaps the best evidence of possible long-term detrimental effects of windrowing are results of an analysis by Fox and others (1985) of adjacent 31-year-old loblolly pine stands growing on a North Carolina Piedmont site, half of which had been burned and the other half windrowed. The stand on the portion of the site prepared by burning had a site index (base age 25) that was 16.4 feet higher than the stand on the adjacent windrowed area; the stand volume was almost 1.5 times greater. This treatment effect probably represents the extreme since an earlier report on the progress of these stands by Glass (1976) indicated that a considerable amount of topsoil had been scalped and deposited in the windrows.

Disc harrowing reduces the amounts of competing woody and herbaceous weeds, but it also prepares a forest site for planting by loosening naturally dense or compacted soils. Foil and Ralston (1967) demonstrated a negative

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linear relationship between root weight and bulk densities ranging from 0.8 to 1.4 $g/cm^3$. Dense soils limit gas exchange and available water, and physically retard root growth. However, Pehl and Bailey (1983) reported that positive early responses of a loblolly pine stand to discing in Georgia were hardly detectable by age 10. It is possible that the initial loosening effect that discing has on soils with poor structure decreases with time as rainfall puddles and recompacts soils that have no protective litter layer.

With the prospect of possible site productivity and yield declines after a well-documented early positive response to shearing, windrowing, and discing, the objective of this study was to assess the benefits of a similar but alternative treatment consisting of shearing, followed by discing and slash displacement between tree rows using a V-blade attached to the tractor pulling the tree planter.

## Methods

A complete description of the Champion International Corporation—Virginia Tech Cooperative Site Preparation Project was described in detail by Lantagne and Burger (1983). The study involves seven site preparation treatments replicated at twelve sites in the South Carolina and Georgia Piedmont. This report concerns only four of these treatments: 1) shearing, windrowing, and discing (shear-windrow-disc); 2) shearing and windrowing (shear-windrow); 3) shearing and discing (shear-disc); and, 4) shearing, V blading and discing (shear-V blade-disc). The shear-disc and the shear-V blade-disc treatments were both designed to provide soil tillage, while allowing the harvest slash to remain on site. The debris was aligned into "mini-windrows" on 10-foot centers with a V blade during site preparation on shear-V blade-disc treatment areas, and by a V blade on the planting tractor on shear-disc treatment areas.

For this study, nine trees were selected in each treatment area at eight study sites, resulting in a total of 72 sample trees per treatment. Because no significant differences were found between the shear-disc and shear V-blade-disc treatments with respect to tree growth or soil measurements, data were averaged to simplify the interpretation of treatment effects. Combining these two treatments (hereafter referred to as "shear-disc") produced a sample size of 144 trees.

The soil was intensively sampled around each tree in an effort to determine which soil/site factors were having the greatest effect on tree growth. Soil bulk density and litter samples were taken at four locations around each tree. Two samples were collected from within the planting row (on each side of the tree). Two samples were collected between planting rows.

## Results and Discussion

After four years, tree volume index in the shear-windrow-disc treatment plots was significantly larger than that in the shear-windrow treatment plots (Table 1). Volume index in the shear-disc treatment plots was not significantly different from the others. These differences among treatments follow the same pattern reported after the first and third growing seasons (Lantagne and Burger, 1983; Stafford et al., 1985). Better growth on the shear-windrow-disc plots compared to the shear-windrow plots has been attributed to soil loosening and elevated levels of soil nutrients resulting from the incorporation and subsequent mineralization of the litter layer. Growth during the first four years on the shear-disc plots may have been slightly lower than on shear-windrow-disc plots due to some soil scalping by the V-blade on the planting tractor. Where scalping occurred, seedlings did not receive the benefit of soil tillage and were often planted in dense subsoils.

There is evidence that the greater initial growth rate of trees in the shear-windrow-disc plots is beginning to diminish after four years. Height increment for the fourth year was identical for all treatment plots. All treatments resulted in an average height increase of about 36 in (Table 1). Furthermore, when expressed as a percent increase in total height, the shear-windrow-disc plots had the lowest relative growth. In the study by Fox and others (1985), stem analysis revealed that growth on the windrowed site started to decline relative to the burned site at age eight.

Table 1. Effect of site preparation treatment on 4-year-old tree volume and 4th-year height increment

| Site Preparation Treatment | Volume Index | 4th Year Growth: Height | 4th Year Growth: Relative |
|---|---|---|---|
| | $in^3$ | in | % |
| Shear, Windrow | 380 b[2] | 37a | 93 a |
| Shear, Disc | 442 ab | 36a | 79 a |
| Shear, Windrow, Disc | 540 a | 36a | 66 a |

[1]Volume Index = $(\text{Diameter})^2 \times$ Height.

[2]Values within a column followed by a different letter are significantly different ($P \leq 0.05$).

Beneficial effects of tillage on surface soil bulk density was probably a causal factor for superior growth on the shear-windrow-disc plots during the first four years. However, bulk density samples collected after the fourth season indicate that the initial effects of tillage are no longer apparent (Table 2). Bulk density samples collected within the planting rows were approximately 1.25 $g/cm^3$ for all treatments. There was no difference between the shear-windrow-disc and shear-windrow treatments with respect to bulk density between planting rows; however, the shear-disc treatment had between-row bulk densities that were lower than both of these treatments. Bulk density samples collected between planting rows in the shear-disc treatment plots averaged 0.16 $g/cm^3$ lower than samples collected within the row. Lower between-row bulk densities in shear-disc treatment plots resulted for two reasons: 1) some scalping within rows occurred during planting; and, 2) organic debris that was left on site between rows protected loosened soil from the compacting and puddling effects of rainfall.

Litter samples collected after the fourth growing season show that the shear-disc treatments have more organic matter on the site (Table 3), with almost three times as much litter between rows compared to windrowed plots. It was apparent during sampling that where these mini-windrows existed, underlying soil tilth remained excellent.

With time, we expect pine roots in the shear-disc treatment areas to fully exploit the loose soil beneath this litter, resulting in more rapid growth of trees than might be expected in the shear-windrow-disc or shear-windrow plots. In addition to the beneficial effects of a looser soil, the "mini-windrows" should result in greater levels of available soil moisture by reducing runoff, by providing increased levels of organic matter to hold moisture, and by protecting the surface from the drying effects of sun and wind. Furthermore, residual logging debris should act as a slow-release nutrient source, releasing N and other essential elements to the trees as decomposition occurs. This slow release should become important as the stand approaches closure and nutrient demands reach a peak. In contrast, growth of the trees on the shear-windrow-disc treatment areas could decline relative to growth of trees on shear-disc treatment areas since most of the N reserves on these plots was removed by windrowing or released by the initial mineralization of the litter layer. Rotation-length studies are needed to confirm the preliminary results from this and other studies. In the interim, foresters should strive to prescribe site-specific treatments that enhance site quality at the lowest cost.

Table 2. Effect of site preparation treatment on soil bulk density within and between the rows

| Site Preparation Treatment | Surface Soil Bulk Density ($g/cm^3$) within-row | between-row | difference |
|---|---|---|---|
| Shear, Windrow | 1.26 a [1] | 1.19 a | 0.07 b |
| Shear, Disc | 1.24 a | 1.11 b | 0.16 a |
| Shear, Windrow, Disc | 1.22 a | 1.20 a | 0.02 b |

[1]Values within a column followed by a different letter are significantly different ($P \leq 0.05$).

Table 3. Effect of Site Preparation Treatment on Surface Organic Debris

| Site Preparation Treatment | Surface Organic Debris ($g/m^2$) within-row | between-row | difference |
|---|---|---|---|
| Shear, Windrow | 390 b [1] | 579 b | 189 b |
| Shear, Disc | 505 a | 1399 a | 894 a |
| Shear, Windrow Disc | 381 b | 455 b | 74 b |

[1]Values within a column followed by a different letter are significantly different ($P \leq 0.05$).

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# SUBSOILING IMPROVES GROWTH OF TREES ON A VARIETY OF SITES[1]

Charles R. Berry[2]

Abstract.--Subsoiling significantly improved early growth of loblolly and shortleaf pines (19 and 38 percent, respectively, after 5 years) on a severely eroded Piedmont site in Georgia. At the Savannah River Forest Station in South Carolina, subsoiling improved growth of loblolly pine on a borrow pit (43 percent after 7 years), and sweetgum on an Orangeburg soil (47 percent after 2 years). Subsoiling was consistently better for tree growth than disking. Roots of loblolly pine grew to the bottom of a subsoiled trench (up to 1 m) in 2 years, but they did not go deeper than about 15 cm on plots that had only been disked. Trees have grown faster on plots amended with sewage sludge than on plots amended with fertilizer.

## INTRODUCTION

Deep subsoiling, i.e., ripping to a depth of 60 cm or more, has been used to a limited extent as a means of preparing problem sites for planting tree seedlings. Sites needing such treatment and the specific benefits of treatment, however, have not been well defined.

Moehring (1970) recommended subsoiling to alleviate compaction damage and to break up shallow hardpans and impervious subsoil layers. Wilson (1969) advocated such treatment for soils in New Zealand, and Page (1977a, 1977b) compared subsoiler designs for use in New Zealand. Schroder (1975) found that although effects of subsoilng persisted for up to 2 years, effective field moisture capacity was not improved. Guild (1971) showed that in New Zealand subsoiling improved survival and, in some cases, height growth of planted Monterey pine (*Pinus radiata* D. Don). The Cities Service Company, and more recently the Tennessee Chemical Company, have used deep subsoiling as a site preparation method for tree planting in the Tennessee Copper Basin (James George, pers. commun. 1983). In numerous reclamation research studies by the U.S. Forest Service in the southeast, subsoiling has been employed as a site preparation method with generally favorable responses (Berry 1977, 1979a, 1982, 1983; Berry and Marx 1978; Kormanik and Schultz 1985; Ruehle 1980).

Subsoiling is regarded by some as a beneficial part of site preparation for the establishment of trees and is carried out routinely by timber companies such as Weyerhaeuser (John Mexal, pers. commun. 1983) and Union Camp (Robert Herren, pers. commun. 1983). Recently the Champion-International Paper Corporation initiated subsoiling field trials (David Oliff, pers. commun. 1983).

Berry (1979b) found that growth of both shortleaf (*P. echinata* Mill.) and loblolly (*P. taeda* L.) pines could be significantly improved by subsoiling with furrows 0.8 m apart and 0.6 to 0.8 m deep on a severely eroded site (Madison soil series). In a borrow pit reclamation study it was found that after 4 years subsoiling improved growth of loblolly pine and that depth was more important than spacing of furrows or whether furrows were parallel or in a grid pattern (Berry 1985).

This paper reports more recent data from these two studies, conducted on low-quality sites, and gives 2-year data from a third study carried out on a high-quality site.

The primary objective of earlier work leading to these experiments was the development of techniques for reclamation of adverse sites. In numerous experiments, including two of the three described in this paper, sewage sludge was tested as an amendment. It is now obvious from these data as well as data from other experiments that well-incorporated sewage sludge followed by deep subsoiling constitutes a superb site preparation treatment (Berry 1977, 1979a, 1979b, 1982, 1983; Berry and Marx 1978, 1980). For this reason it is necessary to comment rather extensively on the effects of sewage sludge both alone and in combination with subsoiling.

In all cases, sewage sludge produced faster tree growth than fertilizer for periods of from 2 to 10 years, the periods covered by these studies. In sewage sludge studies, where a "no treatment" control was installed in addition to a fertilizer treatment (Berry 1986), it was found that a single application of 560 to 1,120 kg/ha of 10-10-10 plus 2,240 kg/ha of dolomitic lime produced little, if any, increase in growth over the control plots.

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Measurements of height and DBH or root-collar diameter of trees were taken in all studies. When root-collar diameter was obtained, values for $D^2H$ (root-collar diameter$^2$ x total height) were computed and all data summarized. $D^2H$ has been shown to be a reliable surrogate measure for aboveground biomass for loblolly pine and it also appeared to be a useful surrogate measure for stem weight and stem volume (Hatchell and others 1985).

## MADISON SOIL EXPERIMENT

### Methods

This experiment was installed in Elbert County, Georgia, where low-quality mixed hardwoods and pines had been harvested within the previous 6 months. After harvesting, the site was root-raked and windrowed. The soil was classified as Madison series and texture of the topsoil was sandy clay loam in two of the three study blocks and sandy loam in the third. Erosion had been extensive on this "littleleaf" site because of poor agricultural practices in the past, and on many plots most of the original topsoil was gone.

A split-plot design with three replicate blocks was employed. Half of each block was subsoiled (major plots). Subsoiled furrows were spaced 0.8 m apart and 0.6 to 0.8 m deep. Each block contained eight minor plots, with half of each plot in the subsoiled area. Four randomly selected plots in each block were planted with 1-0 loblolly pine and four with 1-0 shortleaf pine seedlings. Spacing was maintained at 3.0 m between rows and 1.5 m within rows without regard to furrows. Subsoiling was carried out in late winter just before planting. Minor treatments applied to each species were (1) control (no treatment), (2) 8-cm-deep broadcast application of pine bark prior to subsoiling, (3) sowing of *Lespedeza sericea* (Thumb.) Benth. (67 kg/ha), and (4) interplanting with black locust (*Robinia pseudoacacia* L.).

Loblolly pine, shortleaf pine, and black locust seedlings were obtained from Georgia Forestry Commission nurseries and planted in early March. Many seedlings did not survive planting shock and a spring drought, so vacant spaces were replanted in late April.

Fusiform rust incidence was recorded after 3 years. After 5 years, height, root-collar diameter, and survival were recorded. All data were subjected to an analysis of variance.

### Results

After 5 years, growth of pines had not been improved by bark applications, interplanting with black locust, or sowing *Lespedeza sericea*. The bark that was available for the study, even though it was several years old, contained a lot of undecomposed wood chips. For at least the first 2 years, growth of pines in bark-treatment plots was retarded because of competition for soil nitrogen by wood-decay microorganisms. Although the long-term effects of this treatment may be positive, no benefits could be detected when data were taken.

Subsoiling, however, was beneficial to both loblolly and shortleaf pines. With loblolly, subsoiling increased height growth by 3.5 percent and root-collar diameter growth by 9.4 percent, and the resulting increase in $D^2H$ of 19.3 percent was statistically significant (table 1). Subsoiling increased height growth of shortleaf by 17 percent, root-collar diameter growth by 15 percent, and $D^2H$ by a significant 38 percent over controls after 5 years.

## BORROW PIT EXPERIMENT

### Methods

This study was installed on a borrow pit originally overlain with Gunter sand. During the creation of the borrow pit, several feet of soil were removed, exposing a compact subsoil and thus creating site conditions too severe for economical timber production. All vegetation, consisting mostly of scrubby pines, was removed with a bulldozer. Eighteen treatments (2 amendments x 9 mechanical site preparation treatments) were randomly assigned to 15.5 x 15.5 m plots in each of five blocks. Plots were separated by aisles 8 m wide. Anaerobically digested sewage sludge containing 1.8 percent N, 0.71 percent P, 0.024 percent K, 366 ppm Mg, 117 ppm Fe, 93 ppm Mn, and 53 ppm Zn was obtained from Macon, GA. Sludge was analyzed for nitrogen by Kjeldahl, and all other elements by extraction with concentrated $HNO_3$ and analysis by Plasma Emission Spectrograph at University of Georgia laboratories. Sewage sludge was applied to nine plots in each block at a rate of 17 Mg/ha. Fertilizer (10-10-10) and pulverized dolomitic limestone were applied at a rate of 1,121 kg/ha and 2,242 kg/ha, respectively, to the remaining nine plots in each block. Amendments were applied in September 1978 and incorporated by double-disking to a depth of 15 cm.

Nine physical treatments were carried out on both fertilized plots and plots amended with sewage sludge in each block. The mechanical site preparation treatments were carried out as follows:

(1) Disking only (no subsoiling).
(2) Disking plus subsoiled furrows in one direction, 110 cm apart, 92 cm deep.
(3) Disking plus subsoiled furrows in one direction, 110 cm apart, 46 cm deep.
(4) Disking plus subsoiled furrows in one direction, 220 cm apart, 92 cm deep.
(5) Disking plus subsoiled furrows in one direction, 220 cm apart, 46 cm deep.
(6) Disking plus subsoiled furrows in two directions, 110 cm apart, 92 cm deep.
(7) Disking plus subsoiled furrows in two directions, 110 cm apart, 46 cm deep.
(8) Disking plus subsoiled furrows in two directions, 220 cm apart, 92 cm deep.
(9) Disking plus subsoiled furrows in two directions, 220 cm apart, 46 cm deep.

Table 1.--Effects of subsoiling on survival and growth of loblolly and shortleaf pines after 5 years[a/]

| Major plot treatment | Survival after[b/] | | Height | Root-collar diameter | $D^2H$[c/] | Fusiform rust infection | |
|---|---|---|---|---|---|---|---|
| | 2 years | 5 years | | | | *Cronartium* bushes | trees[d/] |
| | - - Percent - - | | cm | mm | $cm^3 \times 10^3$ | - - Percent - - | |
| | | | LOBLOLLY PINE | | | | |
| Subsoiled | 98.1a | 58.3a | 318a | 81a | 22.4a | 11.9a | 6.25a |
| Not subsoiled | 96.1a | 77.6a | 307a | 74a | 18.8b | 5.4b | 12.50a |
| | | | SHORTLEAF PINE | | | | |
| Subsoiled | 98.0a | 94.8a | 189a | 51a | 5.9a | -- | -- |
| Not subsoiled | 93.9a | 89.6b | 162a | 44a | 4.3b | -- | -- |

[a/] Treatment means within a column followed by the same letter do not differ significantly at $P$ = 0.05.

[b/] *Cronartium* bushes are not included as survivors.

[c/] (Root-collar diameter)$^2$ x height.

[d/] None of these trees are *Cronartium* bushes, but all became infected after planting.

Table 2. Chemical analysis of borrow pit soil 1 year after application of amendments[a/][b/]

| Treatment | N | P | K | Ca | Mg | Mn | Zn | Cu | pH | Organic matter | CEC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | - - - - - - - - | - | - | - | ppm | - | - | - - - - - - - - | | Percent | meq/100 g |
| Fertilizer[c/] disked | 77b | 14b | 16ab | 198a | 89a | 0.27b | 0.07b | 0.02b | 6.04a | 0.23a | 1.60a |
| Sludge[d/] disked | 249a | 50a | 8b | 187a | 13c | 3.09a | 6.98a | 0.29a | 4.38c | 0.23a | 1.86a |
| Fertilizer[c/] disked | 73b | 7b | 22a | 106b | 55b | 0.79b | 0.30b | 0.00b | 5.06b | 0.21a | 1.70a |
| Sludge[d/] disked | 227a | 38a | 8b | 158ab | 17c | 2.50a | 5.43a | 0.21a | 4.46c | 0.38a | 1.92a |

[a/] Treatment means within a column followed by the same letter do not differ significantly at $P$ = 0.05.

[b/] Plots sampled were those not subsoiled (disked) and those which received the maximum degree of subsoiling, i.e., two directions with furrows 110 cm apart and 92 cm deep.

[c/] 1,121 kg/ha 10-10-10 fertilizer and 2,242 kg/ha pulverized dolomitic limestone.

[d/] 17,000 kg/ha (N = 1.8%, P = 0.71%, K = 0.024%).

During the autumn of 1978, the study site was seeded with Ky 31 fescue (*Festuca arundinacea* Schreb.) at 34 kg/ha.

The study site was planted in March 1979 with loblolly pine seedlings (Livingston Parish source) inoculated and heavily colonized (Pt index 88) by the ectomycorrhizal fungus, *Pisolithus tinctorius* (Pers.) Coker & Couch. They were graded to a root-collar diameter of 3.0 to 4.5 mm and a height of 16 to 19 cm. Seedlings were planted at a spacing of approximately 2.2 m x 2.2 m and always in a subsoiled furrow except on disked-only plots. No weed control was necessary.

Growth data were collected in the autumn of 1982 and 1985. Soil was analyzed 1 year after planting. A soil sample composited from five subsamples per plot taken at a depth of 0 to 15 cm was airdried at room temperature for 10 days and chemically analyzed after double acid extraction (0.05 N HCl + 0.025 N $H_2SO_4$). P was determined colorimetrically and cations by atomic absorption. Total N was determined by Kjeldahl, organic matter by wet oxidation chromic acid digestion, CEC by saturation with $NH_4^+$ and replacement with $K^+$, and pH by a glass electrode in a mixture of two parts water and one part soil.

All data were subjected to analysis of variance, and treatment means were evaluated with Duncan's new multiple range test ($P = 0.05$). Survival data were subjected to arc sine transformation.

Results

After 1 year, soil N, P, Mn, Zn, and Cu were significantly higher in sludge plots than in fertilized plots. Soil in fertilized plots had slightly more K and Mg and a higher pH than in sludge plots. Ca and Mg were higher in soil in fertilized disked plots than in fertilized subsoiled plots. Organic matter and cation exchange capacity were unaffected by treatment (table 2).

Several constituents of foliage were also affected by amendment. Trees grown in sludge-amended plots had higher foliar N, Mn, Ba and, on disked plots, Zn than on fertilized plots. Trees on fertilized plots had more K and Mg than on sludge plots.

The effect of sewage sludge on growth after 4 years was striking. Trees on these plots grew an average of 37 percent more in height and 76 percent more in diameter at breast height (DBH) than trees grown on fertilized plots (table 3). Four-year survival was not influenced by treatment.

Subsoiling interacted with amendments to produce different effects on tree growth. On fertilized plots, after 4 years trees grew 9 percent more in height and 17 percent more in diameter on plots subsoiled 46 cm deep than on plots subsoiled 92 cm deep. When sewage sludge was used, however, there was significantly more growth, i.e., 4.5 percent more height and 7.4 percent more DBH when plots were subsoiled to a depth of 92 cm rather than 46 cm (table 4). No growth differences due to spacing of furrows or number of subsoiling directions could be detected after 4 years (table 5).

Seventh-year growth data (table 6) do not show the difference in growth due to subsoiling depth that was evident with fourth-year data. There is still an advantage, however, of subsoiling over disking, particularly on the sludge plots where height, diameter, and $D^2H$ are all significantly higher on subsoiled plots. On fertilized plots, subsoiling improved only height growth.

ORANGEBURG SOIL EXPERIMENT

Methods

This experiment, installed on the Savannah River Forest Station, Aiken, SC, was replicated four times in a randomized complete block design. A split-split-plot design tested three fertility treatments and two mechanical site preparation treatments, i.e., subsoiled versus disked only. The species used was sweetgum (*Liquidambar styraciflua* L.) with two mycorrhizal treatments, *Glomus* spp. versus noninoculated. In an effort to control weeds, Simazine (Princep F-G) was applied (23 kg/ha) in May 1982 and later in the season an application of Roundup(3.7 ℓ/ha as a 1 percent solution). In July 1983 sludge was applied to one-third of the plots at a rate of 34 Mg/ha. Following sludge application in July, all plots were double-disked and in September one-half of each block was subsoiled to a depth of 76 cm with furrows spaced at 122 cm. Furrows were made in only one direction creating parallel lines.

After 2 years, growth data were taken, and soil samples were collected and analyzed. Data were subjected to analysis of variance and means separated by Duncan's new multiple range test.

Results

Survival, not affected by any treatment, ranged from 83 to 88 percent. After 2 years, growth was significantly greater in both sludge and fertilizer treatments than in nonfertilized control treatment (table 7). Height, root-collar diameter, and $D^2H$ on trees in subsoiled plots were significantly greater than on trees in nonsubsoiled plots.

DISCUSSION

Most severely eroded sites, like those common in the Georgia Piedmont or sites otherwise devastated, such as borrow pits, require some mechanical site preparation and the addition of organic or inorganic amendments before they can be effectively reforested. On many such sites, even planting of seedlings is difficult unless the soil has been loosened in some manner. Subsoiling or ripping improves water penetration and internal structure of many soils and facilitates planting, whether by machine or hand.

Table 3.--Influence of amendment on growth of loblolly pine on a borrow pit after 4 years[a]

| Treatment | Survival | Height | DBH |
|---|---|---|---|
| | Percent | cm | mm |
| Fertilizer[b] | 98.4a | 261.2b | 24.3b |
| Sludge[c] | 98.8a | 358.5a | 42.9a |
| % increase due to sludge | | 37.3 | 76.5 |

[a] Treatment means within a column followed by the same letter do not differ significantly at $P$=0.05.

[b] 1,121 kg/ha 10-10-10 fertilizer and 2,242 kg/ha pulverized dolomitic limestone.

[c] 17,000 kg/ha (N = 1.8%, P = 0.71%, K = 0.024%).

Table 4.--Influence of subsoiling depth on growth of loblolly pine on a borrow pit with different amendments after 4 years[a]

| Treatment | Subsoiling depth | Height | DBH |
|---|---|---|---|
| | cm | cm | mm |
| Fertilizer[b] | 92 | 245.8b | 23.2b |
| | 46 | 278.6a | 27.1a |
| % change with increasing depth | | -9.3 | -16.8 |
| Sludge[c] | 92 | 375.4x | 46.0x |
| | 46 | 359.1y | 42.8y |
| % change with increasing depth | | +4.5 | +7.4 |

[a] Treatment means within a column followed by the same letter do not differ significantly at $P$=0.05.

[b] 1,121 kg/ha 10-10-10 fertilizer and 2,242 kg/ha pulverized dolomitic limestone.

[c] 17,000 kg/ha (N = 1.8%, P = 0.71%, K = 0.024%).

Table 5.--Influence of subsoiling on growth of loblolly pines in amended plots after 4 years[a]

| Subsoiling intensity | | | Fertilizer[c] | | Sludge[d] | |
|---|---|---|---|---|---|---|
| Number of directions[b] | Spacing between furrows | Depth of furrows | Height | DBH | Height | DBH |
| | cm | cm | cm | mm | cm | mm |
| 2D | 220 | 46 | 303a | 31.4a | 355a | 42.6b |
| 1D | 220 | 46 | 277ab | 26.2abc | 353a | 43.4ab |
| 2D | 110 | 46 | 275ab | 27.2ab | 358a | 43.4ab |
| 1D | 110 | 46 | 259abc | 23.6abcd | 371a | 43.5ab |
| 2D | 220 | 92 | 260abc | 24.0abcd | 377a | 46.5ab |
| 1D | 220 | 92 | 280ab | 27.6ab | 367a | 45.1ab |
| 2D | 110 | 92 | 233bc | 18.8cd | 389a | 48.8ab |
| 1D | 110 | 92 | 246bc | 22.5bcd | 368a | 43.6ab |
| Disking 15 cm deep | | | 217c | 17.3d | 288b | 30.5c |

[a] Treatment means within a column followed by the same letter do not differ significantly at $P$ = 0.05.

[b] 1D = all furrows running in the same direction and parallel; 2D = furrows running in two directions creating a square grid pattern.

[c] 1,121 kg/ha 10-10-10 fertilizer and 2,242 kg/ha pulverized dolomitic limestone.

[d] 17,000 kg/ha (N = 1.8%, P = 0.71%, K = 0.024%).

The three studies summarized in this paper show that subsoiling can produce greater early growth of trees. Subsoiling produced good results on Madison soil in spite of the fact that the subsoiling was done just before planting in late winter when the soil was moist. The preferred time to subsoil is late summer or early fall when soil is dry. Fall ripping in dry soil produces better fracturing and allows ample time for siltation of furrows to occur before planting in the furrows.

The borrow pit study demonstrates the high value of sewage sludge amendments for stimulating good growth of loblolly pine even on the worst of sites. The rate of application of inorganic fertilizer used in this study did not supply macronutrients in amounts equivalent to that given sludge plots. The rate was high, however, for a single application on a reforestation site. Application of fertilizer at a higher rate would have been impractical, since much of it would have been lost by leaching or washing before it could have been utilized. Split applications of fertilizer are usually an impractical approach for forest regeneration or reclamation. In other research on devastated sites reported earlier (Berry 1982; Berry and Marx 1980), trees growing on plots amended with sewage sludge are maintaining rapid growth at this time (10th year) with no indication of slowing down, whereas trees on fertilizer plots are barely surviving.

Less growth of trees during the first 4 years on fertilizer plots with deep subsoiling (table 4) demonstrates the potential for leaching of nutrients in inorganic fertilizer compared with the organically bound nutrients in sewage sludge. Sludge produced more growth on plots that had received the deeper subsoiling. With both amendments, any intensity of subsoiling produced better growth than just disking (table 5). It was obvious that this response was due to deep root penetration. Four of the eight subsoiling-intensity treatments on fertilizer plots produced significantly more growth than disking only, but on sludge plots, all subsoiling treatments produced tree growth significantly better than on disk-only plots.

Root systems of several trees were excavated after 2 years. In all cases, root penetration was as deep as the depth of the tillage by disking or subsoiling; 15 to 20 cm on disked plots, 46 cm on plots subsoiled to that depth, and 92 cm on plots subsoiled to that depth. On borrow pits that had not been subsoiled, there has been practically no root penetration deeper than a few centimeters, even after 25 years. Good root penetration is important not only for nutrient and water relations but also to allow trees to anchor themselves for support.

The study on Orangeburg soil shows that even on a good site, gains in early growth can be made by subsoiling. It also shows the value of sewage sludge as an amendment on a good site. This is important since future disposal of sludge on land will be less expensive if it is not mandatory to be highly selective in choosing sites.

The main benefits of subsoiling are reduction in bulk density and soil hardness, and in improvements in moisture relations and root penetration which in turn improves uptake of moisture and nutrients and allows better anchorage. Since inorganic fertilizer is lost so rapidly when deep subsoiling is employed, the high cost of hauling sludge becomes more acceptable.

Although analysis did not reveal much difference in growth rate of pine due to intensity of subsoiling in the borrow pit experiment, it should be remembered that the trees are still young and differences may develop, particularly in resistance to windthrow at an older age. Until more information for treatment of denuded sites is available, a good recommendation would be to use a generous application of amendment, sewage sludge if possible, where economics are favorable; incorporate the amendment thoroughly, and subsoil with parellel furrows on the contour with a spacing as needed for the species to be planted. Seedlings should be planted in the furrows. Subsoil as deep as mechanically possible if sludge has been applied, but not so deep — probably no more than 50 cm — if fertilizer is to be used.

Timing is also important and should ideally be in the following sequence: (1) application of amendment--prior to incorporation, (2) incorporation of amendment--prior to subsoiling, (3) subsoil in August or September, (4) plant in February. Subsoiling is most effective when the ground is dry and therefore should be planned for August or September. As much time as possible, up to 6 months, should elapse between subsoiling and planting to allow furrows to close naturally without compaction.

Planting good quality, heavily mycorrhizal seedlings after following the above procedure should virtually assure the rapid establishment of a healthy rapidly growing stand, even on a site as adverse as a borrow pit.

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Chemical analysis of foliage and soil was performed by Carol G. Wells, U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Research Triangle Park, NC.

Table 6.--Influence of subsoiling on growth of loblolly pine on a borrow pit amended with sewage sludge or fertilizer after 7 years[a]

| Subsoiling depth | Survival | Height | Diameter | $D^2H$ |
|---|---|---|---|---|
| | Percent | cm | mm | $cm^3 \times 10^3$ |
| | | FERTILIZER[b] | | |
| Control[c] | 96.0ab | 361b | 52a | 14.5b |
| 46 (4 treatments) | 98.2a | 430a | 66a | 22.7a |
| 92 (4 treatments) | 97.2a | 413a | 61a | 19.5ab |
| $\bar{X}$ (9 treatments) | 97.5A | 415B | 62B | 20.4B |
| | | SLUDGE[d] | | |
| Control[c] | 97.6a | 594b | 94b | 58.0b |
| 46 (4 treatments) | 97.4a | 662a | 108a | 82.9a |
| 92 (4 treatments) | 97.8a | 681a | 111a | 90.9a |
| $\bar{X}$ (9 treatments) | 97.6A | 663A | 108A | 83.7A |

[a] Means within a column followed by the same lowercase or uppercase letter do not differ significantly at $P = 0.05$.

[b] 1,121 kg/ha of 10-10-10 fertilizer plus 2,242 kg/ha of dolomitic limestone.

[c] Disk only, approximately 15 cm in depth.

[d] 17 Mg/ha.

Table 7.--Growth of sweetgum on a good forest site with Orangeburg soil[a]

| Treatment | Survival | Height | Diameter | $D^2H$ |
|---|---|---|---|---|
| | Percent | cm | mm | $cm^3 \times 10^3$ |
| | | MINOR PLOTS | | |
| Control | 85a | 123b | 28b | 1.1b |
| Fertilizer[b] | 83a | 144a | 36a | 2.1a |
| Sludge[c] | 88a | 155a | 37a | 2.4a |
| | | MAJOR PLOTS | | |
| Subsoiled | 88a | 147a | 36a | 2.3a |
| Not subsoiled | 83a | 134b | 31b | 1.5b |

[a] Means within a column followed by the same letter do not differ significantly at $P = 0.05$.

[b] 280 kg/ha of diammonium phosphate.

[c] 34 Mg/ha.

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# Effect of Site Preparation Soil Movement on Loblolly Pine Height Growth in 12-and 14-Year-Old Plantations in the Hilly Coastal Plain of Alabama[1/]

Michael S. Golden and Christopher V. Isaacson[2/]

Abstract--The major objective of this study was to determine whether soil movement from rake-and-pile site preparation has affected height growth of loblolly pine (Pinus taeda L.) plantations in the Hilly Coastal Plain. Soil, topographic, and tree data were taken from 80 tenth-acre sample plots. Stem analysis was performed on one dominant or codominant tree in 60 of the sample plots. Measurements were classified as from windrow, between-windrow, or scalped areas, reflecting the surface soil impacts of the site preparation treatment. Soil bulk densities were higher on the scalped areas, although not severe (1.33 and 1.36 g/cc for the 12-and 14-year-old stands, respectively). Average soil organic matter content was lower and E-horizon depth was less on the scalped than on the between-windrow plots. Although significantly different at the 10 percent level, the trees growing in windrow areas averaged only about one foot taller than between-windrow trees in the 14-year old stand. Tree heights averaged 8.1 and 5.8 ft shorter on the scalped areas than on the between-windrow areas for the 12-and 14-year old stands, respectively. Heights indicated 17.9 and 10.7 ft lower site indexes on the scalped plots for the 12-and 14-year-old stands, respectively.

## INTRODUCTION

Methods of mechanical forest site preparation for planting vary, but one of the more common approaches utilizes some combination of shearing, rootraking or bulldozing, and piling. Although mechanical site preparation in many cases facilitates planting, increases survival (Campbell 1973, Grelen 1959, Hebb 1957, Hu et al. 1980), and may give an early height advantage to young pines (Burns 1973, Derr and Mann 1970, Hebb 1957, McMinn 1969, Worst 1964), concern has grown that long term site productivity may be reduced following some applications (Brendemuehl 1967, Burns and Hebb 1972). Site preparation techniques which may displace topsoil, such as bulldozing, shearing, rootraking or piling, are of greatest concern (Glass 1976, Haines et al. 1975).

This study was designed to document variations in existing loblolly pine (Pinus taeda L.) plantations which may be due to topsoil displacement or other changes which occurred during the site preparation process.

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## METHODS

### Study Areas

After considerable reconnaissance, two large loblolly pine plantations were located which had been site prepared by rootraking and piling and were among the oldest available which were suitable. They were located in Butler County, Alabama, on the Hilly Coastal Plain (Hodgkins et al. 1979). At the time of data collection, one plantation was 14 and the other 12-years-old from planting.

Topography was level to rolling on both sites. Slope percentages ranged from 0-28 percent at the 14-year-old and from 1-14 percent at the 12-year-old stand. The three prevalent soil series found were Smithdale, Luverne, and Boswell, with Smithdale most common. Smithdale soils are fine-loamy siliceoues, thermic Typic Paleudults, typically with sandy loam E horizons and thick Bt horizons that are sandy clay loam in the upper part and sandy loam in the lower part. They are well-drained, with moderate permeability. Luverne soils are clayey, mixed, thermic Typic Hapudults with sandy loam E horizons and clay loam to clay Bt horizons. They are well-drained and moderately slowly permeable. Boswell soils are fine, mixed, thermic Vertic Paleudalfs with thin, fine sandy loam E horizons and clay Bt horizons. They are moderately well-drained, but with very slow permeability. Additionally, small areas of alluvial soils were associated with minor drainages.

The plantation sites had been prepared by shearing and rootraking, with the debris piled

in short, discontinuous windrows. The native stand before harvest and treatment had been mature second growth loblolly pine with a well-developed hardwood understory.

Data Collection and Analysis

Data were collected from 80 tenth-acre circular plots, with 64 and 16 taken in the 14 and 12-year-old plantations, respectively. They were placed using a modified random scheme, where the sites were stratified by topographic classes. Distribution among the topographic strata was as follows:

| Topographic Class | Slope pct | No. of plots |
|---|---|---|
| Ridge | 0-2 | 12 |
| SW slope | 3-10 | 28 |
| NE slope | 3-10 | 8 |
| NE slope | 10-20 | 24 |
| Alluvial | 0-2 | 8 |

Within each plot, the ground surface was delineated into "windrow", "non-windrow", and "scalped" areas based on evidence such as soil piles, depressions, bare exposed subsoil, and ground vegetation. Plots originally located such that a substantial portion was in a scalped area were shifted so that the plot was centered as much as possible in the scalped zone in order to achieve a relatively homogenous condition within the plot. As a result 4 plots in the 14-year-old stand and 3 in the 12-year-old stand were classified as "scalped".

Diameter of each tree was measured with a tape at breast height. The total height of each sixth tree was measured with a height pole. Each tree was designated as "windrow" or "between-windrow" based on its proximity to apparent windrow remains. A tree whose crown area, projected to the ground, came in contact with a windrow was classified as a "windrow" tree.

A modified form of stem analysis was conducted on one dominant or codominant tree from 44 plots in the 14-year-old stand and all 16 plots of the 12-year-old stand. A tree selected for analysis was felled by cutting at ground level. Each year's height growth was delineated by interpreting growth flushes, beginning at the tip and working back toward the butt. Although loblolly pine has a variable number of height growth flushes each year (typically 3 or 4), each season's flushes usually occur in a readily recognizable pattern. The first flush will normally be the longest of the season, and the beginning of this flush will usually be marked by a relatively large, persistent limb whorl. Subsequent flushes will be progressively shorter and the associated limb whorls smaller and less persistent. Thus the tip location at the end of each growing season is indicated by a whorl of relatively larger limbs preceded by a short internode and followed by a long one, with succeeding shorter ones. This recurring pattern is most visible in younger trees, and has been used to provide a more precise reconstruction of yearly tip heights than is possible with conventional stem analysis (Wakeley and Marrero 1958, Trousdell et al. 1974).

Soil profiles were examined and samples for laboratory analysis were taken using a bucket auger. Where windrows or scalped areas occupied less than 15 percent of the plot, three profile samples were taken to a depth of 22 inches. However, when such conditions occupied more than 15 percent of the plot, two samples were taken from the windrows or scalped areas and two from the rest of the plot. Four bulk density samples were taken from the surface 3 inches of each plot with a 3 inch diameter ring and analyzed using the core method described by Blake (1965). Due to difficulty with voids and incorporated organic matter, the bulk density samples from windrows were not used.

Soil profile samples were air dried, ground, and passed through a 2 mm sieve. Soil texture was determined using the Bouyoucos hydrometer method (Day 1965). Soil pH was measured using a 1:1 soil-water mix (Peech 1965). Soil organic matter was determined by the Walkley-Black method (Jackson 1958).

Plot characteristics means for the windrow and between-windrow (scalped areas excluded) areas were compared for each stand using an overall t-test and a paired t-test procedure (Steele and Torrie 1960, Draper and Smith 1966). On each plot, a tree height plot mean was determined for a class whenever two or more trees of the class were present. A significance level of 10 percent was used, due to high variability in the data.

## RESULTS AND DISCUSSION

Table 1 presents a comparison of the soil characteristics and non-pine vegetation means which differed significantly (10 percent level) across condition classes within a stand. The profile textures and pH's were not different.

Soil organic matter and E horizon thickness show clearly the results of removing topsoil from the scalped areas and of pushing topsoil into the windrows. Values are considerably higher in the windrows and somewhat lower in the scalped areas. The E horizons of the windrows are actually conglomerations of materials which were pushed into the windrow piles. Thus they may consist of mixtures of E, B, and even C horizon materials, as well as organic debris.

TABLE 1.--Plot averages for significant soil and vegetation characteristics of the two plantations

| Plantation | Soil Bulk Density[a] | Soil Organic Matter[b] | E Horizon Thickness | Non-Pine Woody Plants |
|---|---|---|---|---|
| | (g/cc) | (pct) | (in.) | ($ft^2$/A) |
| 14-year | | | | |
| Between-windrow | 1.20 | 1.63 | 11.0 | 5.58 |
| Scalped | 1.36 | 1.05 | 8.8 | 3.95 |
| Windrow | --- | 2.05 | 23.1 | -- |
| 12-year | | | | |
| Between-windrow | 1.27 | 1.45 | 8.6 | 4.88 |
| Scalped | 1.33 | 0.93 | 7.4 | 2.47 |
| Windrow | --- | 2.32 | 25.8 | -- |

[a]Surface 3 inches.
[b]Top 22 inches.

Soil bulk density comparisons of the surface 3 inches of the scalped and between-windrow areas reflect the residual effects of compaction during the mechanical treatment and perhaps by subsequent raindrop action on the persistent bare soil of the scalped areas. Although the scalped area bulk densities of 1.36 and 1.33 g/cc in the 14 and 12-year stands, respectively, are not extreme, they do reach or exceed the 1.33 g/cc level found by Foil and Ralston (1967) to severely restrict loblolly pine root growth on loamy sand Coastal Plain soils. Some recovery from compaction should have occurred since treatment through the action of plant roots and soil organisms, so the immediate post-site preparation bulk densities must have been higher.

The scalped areas are particularly conspicuous due to their much more open appearance compared to the surrounding area of each plantation. The basal areas of the non-pine woody understories reflect this, being considerably lower on the scalped areas. Some understory species differences were also apparent. Shrubs of the genus Vaccinium were more prevalent on the scalped areas than elsewhere, and grasses were more abundant as well.

Although the average tree heights were significantly taller in the windrows than in the between-windrow areas, the difference averaged only 1.0 ft. Part of the reason for this unexpectedly small difference is probably the difficulty in defining the extent and influence of the windrows. The windrows encountered on these sites were commonly not straight or even linear. They sometimes occurred as disconnected piles, and their boundaries were not distinct.

Tree height differences between the scalped and between-windrow trees were much more distinct, as shown below:

| | Mean tree heights | |
|---|---|---|
| | Age 14 plots | Age 12 plots |
| | (ft) | (ft) |
| Non-scalped | 41.1 | 38.4 |
| Scalped | 35.3 | 30.3 |
| | ---- | ----- |
| Difference | 5.8 | 8.1 |

These height differences were significant, and clearly indicate the potential reduction in productivity that is possible where extremes of improper treatment occur. Figures 1 and 2, developed from the stem analysis data, illustrate that the divergence between scalped and between-windrow tree heights developed early and was continuing at the last ages measured.

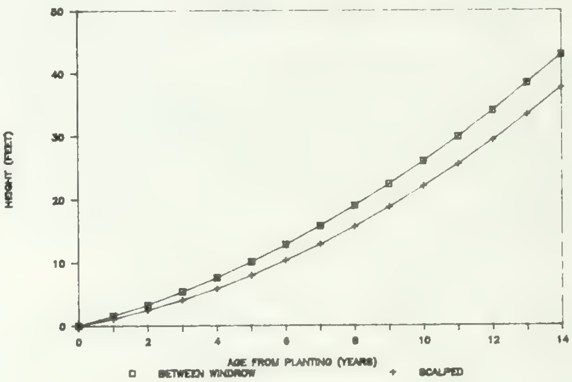


Figure 1.--Average dominant pine height growth curves for between-windrow and scalped plots in the 14-year-old plantation.

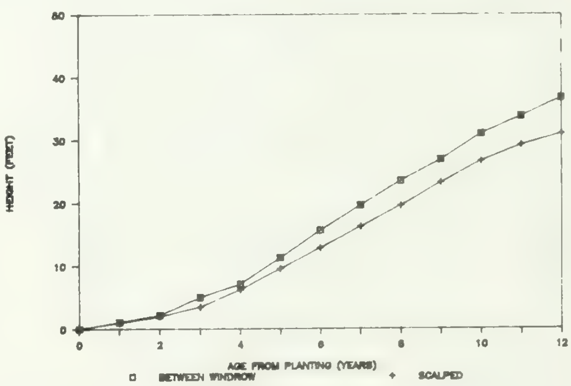


Figure 2.--Average dominant pine height growth curves for between-windrow and scalped plots in the 12-year-old plantation.

Site index differences between the scalped and between-windrow stands are even more striking. Estimated 25-year site indexes based on the heights measured (Amateis and Burkhart 1985) are:

| | Site index (25-year) | |
|---|---|---|
| | 14-year stand (ft) | 12-year stand (ft) |
| Between-windrow | 67.2 | 73.5 |
| Scalped | 56.5 | 55.6 |
| Difference | 10.7 | 17.9 |

Diameter differences, although significant, were less striking. Average dbh for the between-windrow and scalped areas in the 14-year plantation was 5.9 and 5.3 inches, respectively. Possibly the reduced competition on the scalped plots contributed to the diameter growth differences being less spectacular than those for height.

These scalped areas represent the extreme of treatment conditions. Of the 80 plots randomly placed, 7 (8.8 percent) were in scalped areas. Although this may not be considered a good estimate of the total plantation area in a scalped condition, it does not seem unreasonable. Personal observation indicates that most recent rake-and-pile site treatments result in less of such severe conditions. Avoiding such severe scalping of topsoil seems to be primarily dependent upon machine operator care and skill.

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# 10-YEAR OLD PLANTATION ATTRIBUTES AS AFFECTED BY HARVESTING AND SITE PREPARATION METHODS[1/]

G. Kenneth Xydias[2/]

Abstract.--Paired plots of approximately five acres in size were harvested in 1975-76 by either a whole tree or by a stemwood harvest at six locations in Virginia and two locations in Georgia. These areas were then prepared either by chopping and burning or by harrowing, and then planted. Harvesting method had little effect upon stand attributes at age 10 at those locations prepared by chopping and burning. Whole tree harvest areas that were harrowed had taller trees, more trees, more pine basal area, and less hardwood basal area than the companion plot that was harrowed following stemwood harvest. A possible explanation for this is that the whole tree harvest removed enough of what would have been logging debris to permit the harrowing operation to be more effective.

The growth and yield of planted stands is a complex process, and is one affected by many interrelated factors. Major ones include the inherent potential of the site to provide both water and nutrients, pine stocking and the extent to which competing vegetation is controlled.

Coile (1955) in his classic review of soil factors affecting site index, concluded that soil factors affecting water supply such as texture and depth to horizons limiting root penetration were of paramount importance. More recent work with region-wide studies installed on a wide variety of sites by members of the North Carolina State Tree Nutrition Cooperative have clearly shown that mid-rotation growth of loblolly pine (Pinus tadea L.) can be increased on most piedmont sites by an application of nitrogen (N), and either N or a combination of N and phosphorous (P) on coastal plain sites (Ballard, 1980). Control of herbaceous vegetation shortly after planting has increased early growth rates (Creighton and Zutter 1985), and this increase has been shown to persist for many years (Creighton et al. 1985, Schmidtling, 1984). Control of understory and mid-story woody stems has also increased the growth of the pine overstory (Rheny et al. 1986), and so has pine release (Glover and Dickens, 1985). A preliminary attempt has been made to model the influence of competing hardwood on pine growth (Burkhart and Sprintz, 1984), and this suggests that its effect is substantial.

A variety of site preparation techniques have been used to prepare a site for planting, and have been the subject of numerous studies and reviews (Broerman et al. 1983, Sarigumba 1984, Burger and Kluender 1982), Cruthfield and Martin (1982) pointed out that the purpose of site preparation are to 1) remove logging debris for increased plantability, 2) control competing vegetation, and 3) improve the microsite. They recommended that methods be selected that meet more than one of these criteria. Site preparation methods can either promote or retard plantation growth depending upon the ability of a particular method to control competing vegetation, displace organic matter and topsoil, affect erosion, or influence soil properties (Pritchett and Wells 1978).

Harvesting method is thought to have an effect upon the growth of the future stand through its effect on soil physical properties and upon the nutrient reserves of the site. More than half of the nutrients in the above-ground biomass of a thirty-year old stand of planted pine are in the crown, and this proportion increases as stand age declines. Whole-tree harvests remove significantly more nutrients from the site than do conventional stem-wood harvests where the crown is left in place. These relationships have been well documented and concern expressed for the growth of future stands (Pritchett and Wells 1978). Whole tree harvests have also been viewed as a site preparation method by McMinn (1982), although experience has generally shown that planting sites harvested in this manner without some attempt to control hardwood resprouts are likely to result in a poor pine stand.

The efficacy of any particular method of site preparation in meeting the criteria outline by Cruthfield and Martin (1982) is undoubtedly influenced by both the method used and by the amount and type of debris left after harvest. This is influenced by both the nature of the stand being harvested and the degree of utilization of that harvest. Few if any researchers have examined the effect of these factors on pine stand establishment and growth. This paper will report on how the factors of prior stand characteristics, harvesting method, and site preparation method have affected the early development of planted loblolly pine (Pinus tadea L.)

## METHODS

Paired plots of 5-10 acres in size were established in each of eight stands in Georgia and Virginia in 1974. A hundred percent tally of all merchantable trees was done prior to harvest. Plot pairs were then harvested by either a stemwood harvesting system or by a whole tree harvesting

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system. Each plot was then prepared using techniques deemed appropriate for the amount of logging residuals. Study location and site descriptions are given in Table 1, while preharvest volumes and methods of site preparation are summarized in Table 2.

Preparation was done in the spring and summer of 1975, and planting was done during the 1975/76 dormant season. Seven twentieth-acre subplots were randomly established in each of the plot pairs, permanently monumented, and used to estimate planting and survival rates. These subplots were revisited following the second growing season to evaluate pine stocking and average height.

No further work was done until the dormant season of 1985/86 when 4-5 permanent plot pairs were established 75-100 feet on either side of the line separating the two harvesting methods. Information gathered at each plot included pine basal area, height of dominants, and number of trees, and hardwood basal area. Pine basal area was estimated with a BAF 5 prism held over the plot center. Height of dominants was based on the average height of three of the taller trees in the vicinity of the plot center. Pine trees/acre were estimated from a twentieth acre subplot. Hardwood basal area was determined from three BAF 5 subplots located at the ends and center of a 30 foot transect centered on the plot center and oriented at right angles to the rows of planted pine. Stand attributes were tested for significant differences using Student's T-test calculated for a paired plot analysis, except at the Dye tract where plots were not paired.

Table 1.--Study locations and site description

| Tract | Drainage[a] | Region[b] | County | State |
|---|---|---|---|---|
| Cannon | SE | UCP | Burke | GA |
| Cobb | W | P | Amelia | VA |
| Dye | SP | UCP | Jefferson | GA |
| Hayes | W | P | Mecklenburg | VA |
| Miller | SP | UCP | Surry | VA |
| Oschner | SP | UCP | Surry | VA |
| Saunders | W | P | Lunenburg | VA |
| Sou. Plant | W | P | Amelia | VA |

[a]SCS drainage classes: SP = somewhat poorly, w = well, SE = somewhat excessive

[b]Regions: UCP = upper coastal plain, P = piedmont

Table 2.--Preharvest volumes and site preparation methods

| Tract | Pine | Hardwood | Stemwood | Whole-tree |
|---|---|---|---|---|
| | -----Cords/Acre----- | | -------Site Prep[a]-------- | |
| Cannon | 19 | 0 | CB | CB |
| Cobb | 21 | 10 | H | H |
| Dye | 0 | 13 | CB | CB |
| Hayes | 0 | 12 | CB | H |
| Miller | 21 | 4 | H | H |
| Oschner | 15 | 3 | H | H |
| Saunders | 2 | 10 | CB | H |
| Sou. Plant | 11 | 12 | H | H |

[a]Site prep methods: H = harrow, CB = chop/burn

## RESULTS AND DISCUSSION

Planting rates, initial survival, and number of trees after the second growing season are given in Table 3. Survival for the 1976 planting season was excellent in the Georgia locations, but marginal in the Virginia locations except for the Saunders tract. Study sites on the Cobb and Southern Plantation tracts were replanted in the 1977 planting season but stocking figures shown are prior to replanting.

Table 3.--Planting rates, first year survival, and pine stocking at age 2

| Tract | Harvest[c] | Planted | Pct. Surv. | Stocking |
|---|---|---|---|---|
| Cannon | SW | 554 | 97 | 294 |
| | WT | 614 | 98 | 354 |
| Cobb[a] | SW | 520 | 41 | 326 |
| | WT | 514 | 44 | 363 |
| Dye | SW | 574 | 89 | 409 |
| | WT | 507 | 88 | 333 |
| Hayes | SW | 643 | 66 | 351 |
| | WT | 660 | 74 | 420 |
| Miller[b] | SW | 663 | 46 | 346 |
| | WT | 671 | 49 | 368 |
| Oschner | SW | 668 | 58 | 387 |
| | WT | 723 | 69 | 499 |
| Saunders | SW | 786 | 71 | 558 |
| | WT | 694 | 76 | 527 |
| Sou. Plant[a] | SW | 506 | 52 | 414 |
| | WT | 557 | 59 | 520 |

[a]Replanted

[b]Unable to distinguish planted trees from volunteers

[c]Harvest: SW = stemwood, WT = whole tree

Average height of the three tallest trees on each plot at age 2 is given in Table 4. Height differences were not significant at the five percent level for any of the sites with the exception of the Saunders tract. There, trees in the stem wood harvested plot were taller than trees in the whole tree harvest plot.

Table 4.--Average heights of dominants after two growing seasons

| Tract | Stem Wood | Whole tree | Significance[a] |
|---|---|---|---|
| Cannon | -- | -- | -- |
| Cobb | 2.2 | 2.2 | NS |
| Dye | -- | -- | -- |
| Hayes | 3.5 | 3.7 | NS |
| Miller | 2.6 | 2.4 | NS |
| Oschner | 3.1 | 3.4 | NS |
| Saunders | 4.3 | 3.7 | ** |
| Sou. Plant | 2.9 | 2.8 | NS |

[a]NS = not significant, ** = significant at 0.01 level

Means for the various plantation attributes in 1985 are given in Table 5, and probability associated with the observed differences are given in Table 6. At this point, we leave the factual realm, and enter into one of speculation. The questions of interest are: 1) are there any differences in planted stand attributes ten years after harvesting to different degrees of utilization, and 2) what is a reasonable explanation for those differences if they indeed exist.

Observation on both sides of the line separating the two harvest methods on the Hayes and Southern Plantation tracts suggested that large differences occurred. Both tracts had a reasonably well stocked pine stand in the whole tree harvest areas, and what is better described as a plantation failure or a stand that is more hardwood than pine in the area receiving a stemwood harvest. That perception is reinforced by both the stand attribute data of Table 5 and the probability associated with these differences shown in Table 6.

There appeared to be little visual differences in the plantation attributes at the other locations except for the Cobb tract, and that too is reinforced by the data of Tables 5-6. The lack of any difference for the Cobb tract may be due to an inadequate sample size. No plots were established in either of the two location in Surry County, VA, but observations at those sites suggests that there were no differences.

Hardwood basal area were quite similar on both the Cannon and Dye tracts, and significantly greater in the conventionally logged plots on the other tracts. There were no observable differences in hardwood basal area for the Surry County locations.

Table 5.--Plantation attributes in 1986

| Tract | Age | Harvest | Pine BA | Pine Dom.Ht. | Pine Trees | Pine DBH | Hdwd BA |
|---|---|---|---|---|---|---|---|
| Cannon | 10 | SW | 41 | 29 | 264 | 5.4 | 5 |
| | | WT | 60 | 31 | 380 | 5.4 | 3 |
| Cobb | 9 | SW | 22 | 23 | 209 | 4.8 | 25 |
| | | WT | 28 | 24 | 225 | 4.7 | 8 |
| Dye | 10 | SW | 60 | 30 | 420 | 5.1 | 24 |
| | | WT | 69 | 31 | 432 | 5.9 | 28 |
| Hayes | 10 | SW | 23 | 26 | 201 | 4.7 | 34 |
| | | WT | 57 | 29 | 410 | 5.1 | 15 |
| Saunders | 7 | SW | 23 | 20 | 152 | 5.3 | 23 |
| | | WT | 42 | 21 | 224 | 5.8 | 8 |
| Sou. Plant | 9 | SW | 15 | 29 | 101 | 5.2 | 49 |
| | | WT | 66 | 33 | 411 | 5.4 | 27 |

Table 6.--Probability of observed differences in plantation attributes

| Tract | Pine BA | Pine Dom. Ht. | Pine Trees | Pine DBH | Hdwd BA |
|---|---|---|---|---|---|
| Cannon | 10 | 20 | 20 | NS | 20 |
| Cobb | NS | 0 | NS | NS | 1 |
| Dye | NS | NS | NS | 20 | NS |
| Hayes | 5 | 1 | 10 | NS | 1 |
| Saunders | 20 | NS | 10 | NS | 5 |
| Sou. Plant | 5 | 5 | 5 | NS | 10 |

Probabilities are: NS 20.0, 20 = 10.0 - 19.9, 10 = 5.0 - 9.9
5 = 1.0 - 4.9, 1 = 1.0

All of these observations may be reconciled by a hypothesis consisting of the following elements:

1) Plantation performance is dictated by site preparation efficacy for competition control.

2) Site preparation efficacy is influenced by both the amount of residual debris and by the site preparation method.

3) Residual debris is influenced by both the harvesting method and by the composition of the stand being harvested.

The better pine stand in the whole tree harvest plots on both the Hayes and Southern Plantation tracts could be due to more effective site preparation. The Hayes tract was pure hardwood, while the Southern Plantation contained equal volumes of hardwood and pine. The whole tree portion of the Hayes tract was prepared by harrowing and the stemwood harvested portion was prepared by a chop/burn treatment. A better job of hardwood control probably occurred on the whole tree portion of the Hayes tract. Both plots on the Southern Plantation tract were prepared by harrowing. However residual debris on the stemwood harvested plot could have been sufficient to prevent the harrow getting into the ground. Thus this treatment may have been similar to the chop/burn treatment on the Hayes tract.

No differences in pine or hardwood attributes were observed on the Cannon and Dye tracts. The only preparation method used here was a chop/burn treatment. Little hardwood was observed on the Cannon tract because it was essentially absent prior to harvest. The lack of hardwood is also reflected in the level of current hardwood basal area. The Dye tract had a pure hardwood stand prior to harvest and had an abundant amount of hardwood 10 years after planting. The efficacy of a chop/burn treatment on hardwood root kill was not influenced by the amount of residual debris.

Although no data was taken, there appeared to be little difference in pine or hardwood attributes on the Miller and Oschner tracts. Both plots on these tracts were harrowed, but there was only a modest amount of hardwood in the prior stand (Table 2). This hardwood may not have been sufficient to interfere with the efficacy of harrowing.

Results from the Cobb and Saunders tracts do not conform as well to the hypothesis. Both plots on the Cobb tract were harrowed, and there is considerably more hardwood basal area in the plot receiving the stemwood harvest. Plantation attributes generally do not differ significantly by harvest method, although the visual impression is

one of superiority for the whole-tree plot. The sample size may have been too small to detect any difference. Alternatively, two-thirds of the volume prior to harvest was in pine, and the harrow treatment could have been equally effective for each harvest regime.

Although the stemwood harvest plot on the Saunders tract now has significantly more hardwood basal area than the whole tree portion, there are no differences for the plantation attributes. That study area was reprepared by harrowing in the spring of 1979 when stocking in the remainder of the stand in which the study was located was judged to be unacceptable. Much of the residual debris from the stemwood harvested plots would have been partially decomposed by that time and would not have interfered with harrowing. If this is true, then the harrowing was equally effective for each harvest regime.

Results from all locations seem to support the hypothesis that site preparation efficacy for hardwood competition control varies with site preparation method, harvest method, and composition of the prior stand. A major problem of this hypothesis is that it is not supported by measurements of residual debris after site preparation. However, the boundary between the two harvest methods can still be identified in the field by the presence of residual debris on those sites that were predominately hardwood stands prior to harvest.

Major conclusions from this study are as follows:

1) The potential performance of any planted stand is influenced by the composition of the prior stand, the method of harvest, and the method of site preparation, as well as soil characteristics of the particular site.

2) Although whole tree harvesting has the potential of site degradation through removal of the nutrient-rich crown, it can also result in a better stand than a stemwood harvest if it permits use of a site preparation method that does a better job of hardwood competition control.

3) Site preparation methods should be prescribed to meet the objectives of debris removal and competition control based on the conditions of each site.

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EFFECTS OF SITE PREPARATION, FERTILIZATION AND GENOTYPE ON LOBLOLLY PINE GROWTH AND STAND STRUCTURE--RESULTS AT AGE 15[1]

Marilyn A. Buford and William H. McKee, Jr.[2]

Abstract--Five site preparation treatments were imposed on a somewhat poorly drained area having loblolly pine site index of 70 feet (base age 25) on the Santee Experimental Forest in South Carolina: 1) control (no mechanical treatment), 2) v-blade, 3) v-blade and rootrake, 4) v-blade, rootrake, and bed, and 5) v-blade, rootrake and disk. In February 1971, genetically improved and unimproved loblolly pine seedlings were planted at a density of 726 trees per acre. Four fertilizer treatments were tested: 1) control (no fertilizer), 2) 50 lbs P and 200 lbs N, 3) 100 lbs K and 200 lbs N, and 4) 50 lbs P plus 100 lbs K and 200 lbs N. Phosphorus applications increased mean tree heights and diameters through age 15, and application of nitrogen and potassium without phosphorus decreased them. There was a site preparation x genotype interaction in response to site preparation.

Keywords: Pinus taeda, South Carolina

## INTRODUCTION

Understanding the response of loblolly pine plantations of different genotypes to various site preparation treatments and fertilizer regimes is necessary for predicting yields of managed plantations. The study described here was designed to test the main effects and interactions of five site preparation treatments, four fertilization treatments, and two genotypes on the growth, survival, and yield of planted loblolly pine (Pinus taeda L.). McKee and Wilhite (1986) reported some results of this and three similar studies through age ten. This report will describe the results at age 15.

## METHODS

A somewhat poorly drained site (Wahee soil series, Aeric ochraquult, clayey, mixed, thermic) on the Santee Experimental Forest on the South Carolina Coastal Plain was chosen for the study. Before study installation, the site was burned, and merchantable timber was removed in the winter of 1968-1969. Unmerchantable timber was felled and left in place, and the area was burned again in February 1970.

The experimental design is a split-split plot with main plots randomized in two complete blocks. Five site preparation treatments were applied on 1-acre main plots, four fertilizer treatments were applied on 1/4-acre subplots, and seedlings of two genotypes were planted on 1/8-acre sub-subplots. The main plot treatments are: (1) control (no mechanical treatment), (2) v-blade, (3) v-blade and rootrake, (4) v-blade, rootrake and bed, and (5) v-blade, rootrake, and disk. The four subplot treatments are: (1) control (no fertilizer), (2) 50 lbs P and 200 lbs N, (3) 100 lbs K and 200 lbs N, and 4) 50 lbs P + 100 lbs K and 200 lbs N. The levels of fertilizer were chosen after soil and foliar analysis during the first year after planting. The nitrogen was broadcast during the sixth growing season and all other fertilizer was applied during the second growingseasonbybroadcast.Responses to N and P are confounded and cannot be separated.

The sub-subplot treatments were seedlings from two different seed sources: (1) seed production areas in natural stands in Colleton County, SC, and (2) seed orchards in Georgetown and Summerville Counties, SC. The site was planted by hand in February 1971 at a 6 x 10 foot spacing (726 trees per acre). The measurement plots are the interior 40 trees (4 rows of 10 trees) in each sub-subplot. There are two border rows between measurement sub-subplots and 4 border rows between measurement subplots.

Hardwood competition was controlled by hand cutting and spraying the entire study area with 2, 4, 5,-T in September 1970 and August 1972 to maintain hardwood competition at the same level across all treatments. This confounds the growth response to site preparation, since an expected

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result of more intensive mechanical site preparation is decreased hardwood competition. However, the removal of hardwood competition as a factor places the emphasis of early response to site preparation on soil disturbance.

The following variables were calculated from the measurements made at ages 10 and 15 on each sub-subplot: mean height, mean diameter (breast height), mean tree basal area, mean tree volume, total basal area, total volume and number of trees surviving. The volume equation used was:

$$VOB = 0.0039557\ (D^{1.8945})(H^{0.9288})$$

where D = diameter at breast height

H = total height (Clutter et al. 1984).

An analysis of variance to compare treatment effects on tree and stand parameters was performed for all the variables given above at ages 10 and 15. F-statistics for the effects of interest were calculated. Basal area and total volume per acre were plotted by site preparation and fertilizer treatment for ages 10 and 15 and examined.

## RESULTS AND DISCUSSION

### Main Effects

#### Fertilizer

Phosphorus treatments consistently increased all the stand characteristics investigated, with the P-K-N treatments consistently showing the largest response. The response to phosphorus is especially visible in the diameter and height distributions. The diameter and height distributions from the phosphorus treatments are shifted to the right relative to the nonphosphorus treatments (contain higher proportions of larger stems). Examples of actual diameter distributions are given in Figure 1 and 2. There is a significant, consistent and negative effect of the potassium and nitrogen combined treatment on the stand characteristics investigated. Figures 3, 4, and 5 show a consistent advantage over the control (no fertilizer) for phosphorus treatments and a consistent loss compared to the control for the K-N treatment. A possible reason for this loss is increased microbial competition for P in the presence of K and N to the detriment of the trees.

#### Site Preparation

There is no statistically significant site preparation effect on any of the stand characteristics investigated at age 15. However, there is a trend in the response of the stand characteristics to the different site preparation treatments (Figures 3 and 4). Through age 10, response to the v-blade and rootrake treatment was less than the control (Wilhite and McKee 1985, McKee and Wilhite 1986). However, at age 15, the v-bladed + rootraked plots generally had higher basal areas and volumes per acre than the control plots (Figures 3 and 4).

#### Genotype

At ages 10 and 15, mean heights and dominant heights were greater for the seed orchard stock than for the seed production area stock. These genotype effects are consistent over time and can be seen readily in Figure 6. The height advantage of the seed orchard stock over the seed production area is consistent over time and represents a real gain in height over that from the seed production area stock. This same trend exists for dominant height over time.

### Interactions

#### Fertilizer x genotype

At age 10, there is a fertilizer x genotype interaction on mean diameter and on mean tree basal area. The seed orchard stock suffers more of a negative response in mean diameter relative to the control than the seed production area stock for the K + N treatment, and has a larger response relative to the control than the seed production area stock for the P treatments, although the advantage is extremely slight for the P + K treatment, (Figure 7).

#### Site preparation x genotype

There is a site preparation x genotype interaction on basal area/acre and total volume per acre at ages 10 and a somewhat weaker interaction on these two stand characteristics at age 15. The age 10 results indicate that the seed orchard stock does not perform as well as the seed production area stock for the V-blade + rootrake + disk and the V-blade + rootrake + bed treatments. The seed orchard stock performs better than the seed production area stock for the other three treatments at age 10. At age 15, the seed orchard stock performs better than the seed production area stock for the control and V-blade treatments and performs worse than the seed production area stock for the other treatments (Figure 8). The trend would indicate that the seed orchard stock does not respond as well to the more intensive site preparation methods as does the seed production area stock through age 15.

#### Survival

Trends in survival with respect to site preparation show that there were significant differences in initial survival relative to treatment. From ages 10 to 15, the mortality rate has been essentially the same for all treatments except V-blade + rootrake. The lower mortality rate for this treatment is likely a result of less intense competition due to the slower overall growth, particularly that of height, for this treatment.

With respect to fertilizer treatment, mortality rates are essentially equal (parallel survival curves) for all but the K + N treatment. The associated flatter survival curve of the K + N treatment is likely the result of the slower crown expansion accompanying the slower height growth rate of this treatment.

Mortality rates of the two genotypes are essentially the same from age 10 to 15, paralleling their very similar height growth patterns. At age 15, the seed orchard stock maintains a remnant of its initial seedling survival advantage.

CONCLUSIONS

The analyses of variance and graphs of the stand characteristics at ages 10 and 15 on this somewhat poorly drained site indicate that:

1. Survival patterns by treatment parallel the height growth patterns by treatment.
2. The fertilizer x genotype and site preparation x genotype interactions suggest that such interactions found under the low level of genetic selection in this study should be considered when planning genetic tests.
3. Seed orchard stock produced less basal area/acre with increasing site preparation intensity than did the seed production area stock.
4. The V-blade + rootrake site preparation treatment consistently reduced production relative to the control through age 10. V-blade, V-blade + rootrake + disk and

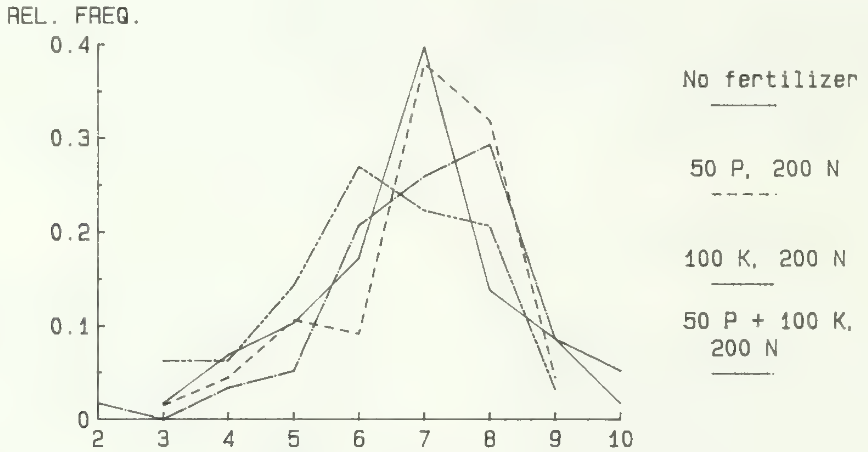


Figure 1.--Relative frequency of diameter at age 15 by fertilizer for no mechanical site preparation (Block I).

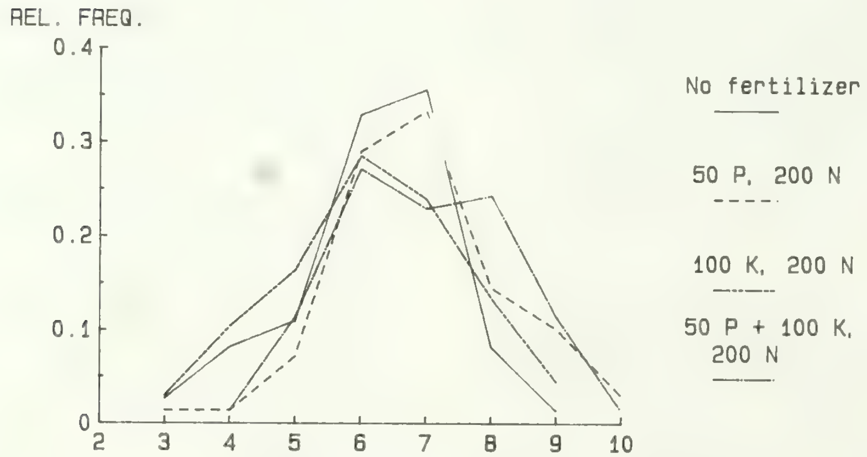


Figure 2.--Relative frequency of diameter at age 15 by fertilizer for v-blade + rootrake + bed (Block I).

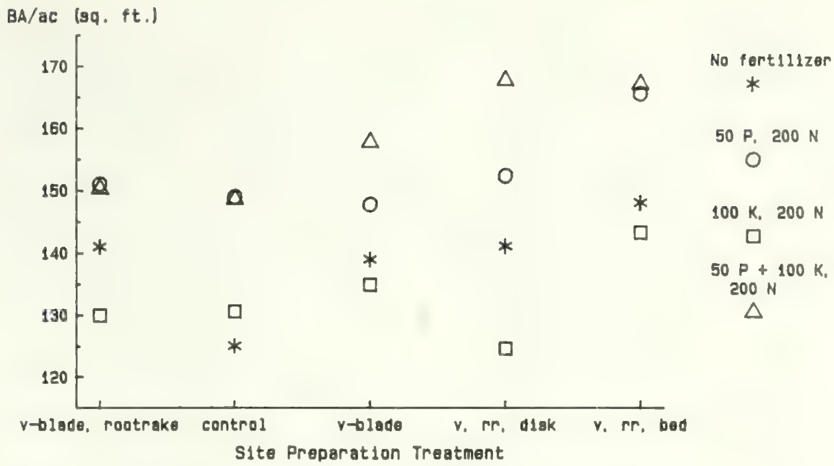


Figure 3.--Basal area per acre by site preparation and fertilizer treatments at age 15.

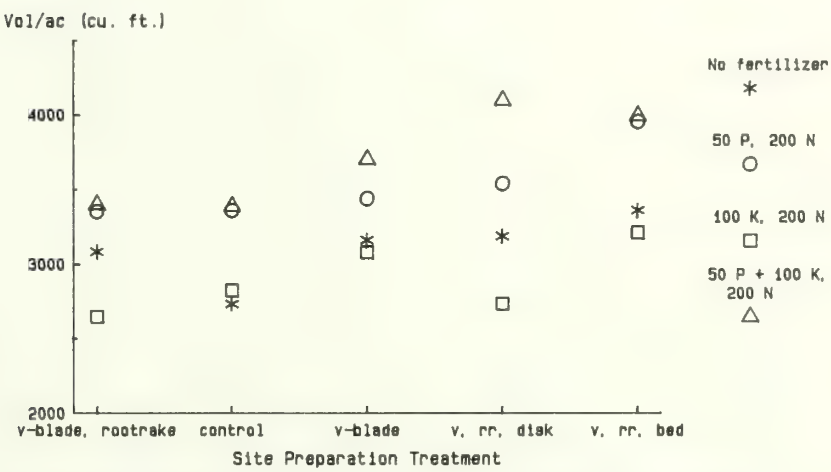


Figure 4.--Total cubic foot volume per acre by site preparation and fertilizer treatment at age 15.

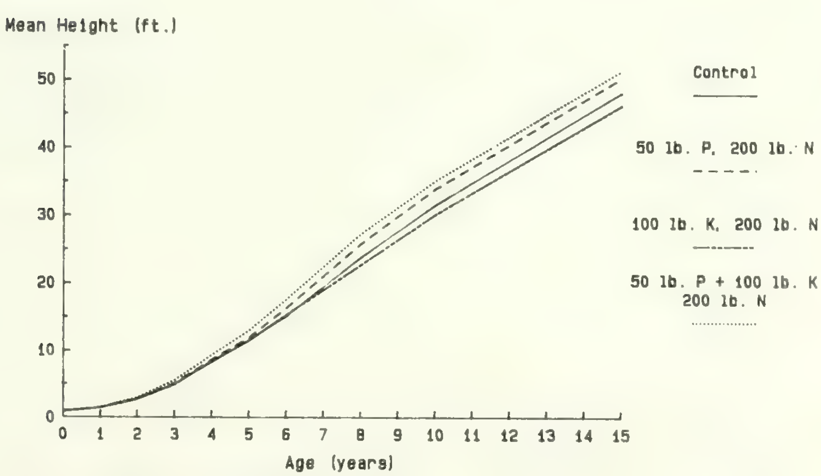


Figure 5.--Mean height through time by fertilizer treatment.

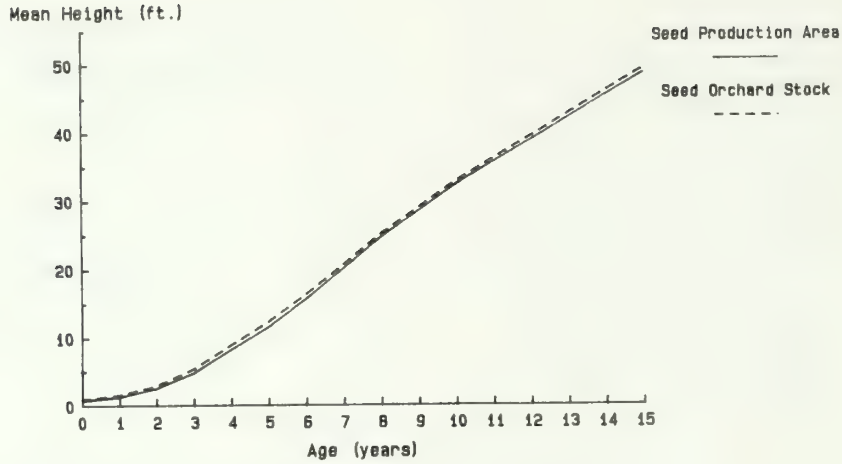

Figure 6.--Mean height through time by genotype.

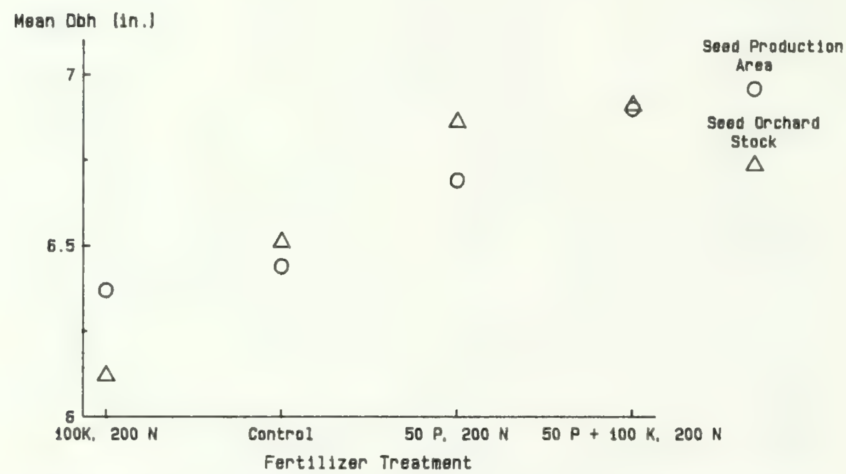

Figure 7.--Mean diameter breast height by fertilizer treatment and genotype at age 15.

Figure 8.--Basal area per acre by site preparation treatment and genotype at age 15.

V-blade + rootrake + bed consistently showed increased production over the control.

5. The fertilizer treatments significantly affected all stand characteristics. The P + N and P + K + N treatments increased the growth of the stand characteristics relative to the control.

6. Great care should be exercised in generalizing results from this study to operational situations because of the chemical hardwood control imposed on all treatments.

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# PHOSPHORUS DISTRIBUTION IN THREE LOBLOLLY PINE PLANTATIONS AFTER DIFFERENT SITE PREPARATION[1/]

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Abstract -- In the summer of 1982, three forest sites at the Reynolds Homestead Research Center on the Virginia Piedmont were clearcut. In the fall of the same year, all three sites were prepared using one of the following treatments: 1. shear,rake, disk (3-passes); 2. chop and burn (high-intensity burn); and 3. shear-disk (1-pass). During March of 1983, 1-0 genetically improved loblolly pine (Pinus taeda L.) seedlings were planted on all sites. After three growing seasons biomass and total P content of planted pines were greatest on the shear,rake,disk site. Total biomass and P content of native vegetation, and forest floor were greatest on the shear-disk area. Total P in the upper 15 cm of mineral soil was also greatest on the shear-disk area. Total system P was highest on the shear-disk area and lowest on the site that was chopped and subjected to the intense fire. Pine height, root collar diameter and volume were best on the more intensively prepared areas and no evidence of P deficiency in planted pines was found for any of the three plantations. Although intensive site preparation methods did influence the distribution of P on these sites, there was no short-term effect on P nutrition or early growth of planted pines.

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## INTRODUCTION

Plantations of southern pines have been shown to respond to P fertilizer on many sites in the lower Coastal Plain (Everett, 1986; Fisher and Garbett, 1980; Pritchett and Smith, 1972; Wells and Allen, 1985; Wells and Crutchfield, 1969; Wells et al., 1973; Wells et al., 1986). But only recently, has evidence been provided of widespread P response on Piedmont sites. Wells and Allen (1985) reported that although individual responses varied considerably, loblolly pine showed an overall mean volume response to P fertilizer application in 49 Piedmont fertilization studies. Since some sites on the Piedmont are apparently deficient in P, it may be important to understand the effects of forest management activities, particularly site preparation, on P distribution if pine growth is to be maximized.

The objective of this study was to determine the effects of three common site preparation methods on site P distribution, tree size, total biomass and overall nutrition of planted pines during the third growing season of three loblolly pine plantations on the Virginia Piedmont.

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[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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## METHODS

During the summer of 1982, three similar forested sites at the Reynolds Homestead Research Center in Critz, Virginia were clearcut. Pre-harvest stand and site characteristics are presented in Table 1. Each area was site prepared using one of the following methods: 1. shear,rake,disk (three passes); 2. chop and burn (high-intensity burn); or 3. shear-disk (one pass). In March of 1983, all areas were planted with 1-0 genetically improved loblolly pine.

The three plantations were reentered during August of the third growing season and 30 to 50 (depending on plantation area) randomly-located sample plots were established on each area. At each sample plot all native vegetation within and above a 1 $m^2$ sampling frame was collected. In addition, the forest floor was sampled and a soil sample was collected below a 23 cm circle to a depth of 15 cm. Living roots were separated from this soil volume and were analyzed separately to obtain estimates of belowground biomass and P content, which were then added to aboveground estimates of native vegetation. The nearest planted pine to each sample plot was destructively sampled for biomass and P content evaluation.

All tissue samples were dried at 65°C for 24 hours and biomass was determined. Subsamples of all soil and tissue samples were digested using a micro-Kjeldahl procedure and were analyzed for total P using a Technicon AutoAnalyzer II.

Pine growth measurements were made in November

Table 1. Pre-harvest stand and site characterization of three forested research areas located at the Reynolds Homestead Research Center, in Patrick county, on the Virginia Piedmont (adapted from Fox, 1984).

| Treatment Area | Ave. Slope (%) | Major Soil Series | [1]Site Index Yellow-poplar (m) | Basal Area ($m^2$/ha) | Total Volume ($m^3$/ha) |
|---|---|---|---|---|---|
| Shear,rake, disk | 17 | Cecil | 28 | 23.8 | 115.9 |
| Chop,burn | 17 | Cecil, Hayesville | 28 | 24.6 | 112.2 |
| Shear-disk | 11 | Cecil | 28 | 22.2 | 121.4 |

[1] Base age 50 years.

of the third growing season. Six to eleven (depending on plantation area) 0.04 ha plots were established in each plantation and height and root collar diameter was determined for all planted pines within the plots. Volume index ($d^2h$) was calculated on an individual tree basis. Estimates of the number of trees per hectare were based on the number of trees found in the measurement plots.

Pine foliage samples used for nutrient analyses were collected during November, following the third growing season, from all trees in the measurement plots described above. Samples consisted of needles from the uppermost fully elongated whorl on the south side of the tree, as recommended by Powers (1984), and Wells and Metz (1963). Nitrogen and P concentrations of this tissue were determined from a micro-Kjeldahl digest using a Technicon AutoAnalyzer II. Cation concentrations were determined from dry-ashed samples using atomic absorption spectrophotometry.

## RESULTS

Total pine biomass (incuding roots) was greatest in the most intensively prepared plantations during the third growing season (Table 2). The shear,rake,disk plantation pine biomass was highest, followed by that of the chop and burn and shear-disk areas. The P content of planted pines directly paralleled biomass.

Biomass and P content of native vegetation were greatest on the shear-disk plantation implying less success at competition control with this treatment but greater success at nutrient conservation (Table 2).

Forest floor biomass and P content were also greatest for the shear-disk plantation. Maintenance of the forest floor during site preparation conserved site P and led to more rapid stabilization of this site (Table 2).

The P content of the surface 15 cm of mineral soil was greatest on the plantation that received the lowest intensity site preparation (Table 3). The shear-disk area had more total P than the other areas even though it also had the lowest bulk density (Table 3).

The shear,rake,disk and chop and burn plantations consistently had the most pines per hectare, had taller trees with larger root collar diameters and had larger volume index values than did the shear-disk plantation (Table 4).

Concentrations of P in pine tissue collected after the third growing season provided no evidence of existing or impending P deficiency in any of the three plantations (Table 5). Phosphorus concentrations of from 0.13 to 0.14 % are well above the 0.10 to 0.11 % range commonly used as a critical P response level for loblolly pine. Levels of other nutrients in pine tissue are also higher than reported critical levels or commonly reported concentrations.

## DISCUSSION

The shear,rake,disk treatment relocated logging debris, the forest floor and some surface soil to windrows during the raking process. Since this material contained P, it is safe to say that a redistribution of site P occurred as a result of site preparation. Since windrows were placed in the drainages and then burned it is likely that some P was lost from the site by localized volatilization (Flinn et al., 1979; Harwood and Jackson, 1975; Kodama and Van Lear, 1980), or afterwards, by ash loss from surface water flow.

The chop and burn area also experienced a redistribution and probable reduction of site P reserves. The fire was very intense and likely volatilized some P contained within the logging debris and forest floor. Other sources of probable P loss were loss of P-bearing ash from

Table 2. Biomass and P content of planted pines, native vegetation and forest floor during the third growing season of three loblolly pine plantations on the Virginia Piedmont.

| System Component | Treatment Area | Biomass (kg/ha) | P Content (kg/ha) |
|---|---|---|---|
| Planted Pines | Shear,rake,disk | 928 | 0.7 |
| | Chop,burn | 659 | 0.5 |
| | Shear-disk | 327 | 0.3 |
| Native Vegetation | Shear,rake,disk | 5,901 | 5.3 |
| | Chop,burn | 5,496 | 4.8 |
| | Shear-disk | 9,885 | 10.3 |
| Forest Floor | Shear,rake,disk | 10,345 | 5.2 |
| | Chop,burn | 14,579 | 2.8 |
| | Shear-disk | 39,597 | 19.1 |
| Totals | Shear,rake,disk | 17,174 | 11.2 |
| | Chop,burn | 20,734 | 8.1 |
| | Shear-disk | 49,809 | 29.7 |

the site by convection currents during the fire and the action of wind and water following the fire. In any event, the forest floor and most logging debris were absent from the site at the time of planting, implying a significant redistribution or loss of P and other nutrients.

The plantation which received the shear-disk treatment experienced little loss of P, other than that directly associated with harvest. All forest floor, logging debris and non-merchantable material was left on the site, resulting in rapid stabilization after site preparation. This treatment was conservative with regard to the maintenance of site nutrient reserves, but failed to achieve adequate competition control.

The two plantations which experienced the most drastic redistribution of P and had potential for P loss, did in fact have lower P levels in surface soil, forest floor and native vegetation after three growing seasons (Tables 2 and 3). Despite this fact, pine growth was best on the more intensively prepared areas and pine foliar P concentrations were apparently more than adequate on all three areas. This implies that P did not limit pine growth in these three plantations at age three, regardless of site preparation effects on P redistribution and loss (Tables 4 and 5).

Table 3. Phosphorus content and bulk density of the surface 15 cm of mineral soil during the third growing season of three loblolly pine plantations on the Virginia Piedmont.

| Treatment Area | Bulk Density ($g/cm^3$) | P content of surface soil (kg/ha) |
|---|---|---|
| Shear,rake,disk | 1.12 | 762.7 |
| Chop,burn | 1.12 | 565.2 |
| Shear-disk | 1.03 | 849.9 |

Table 4. Trees/hectare, height, root collar diameter and volume after three growing seasons for three loblolly pine plantations on the Virginia Piedmont.

| Treatment Area | Trees/ha | Height (m) | Root Collar Diameter (cm) | Volume Index ($cm^3$) |
|---|---|---|---|---|
| Shear,rake,disk | 1,420 | 1.90 | 3.8 | 3,394 |
| Chop,burn | 1,277 | 1.79 | 3.7 | 2,990 |
| Shear-disk | 1,038 | 1.78 | 3.2 | 2,617 |

Table 5. Pine foliar nutrient concentrations at the end of the third growing season of three loblolly pine plantations on the Virginia Piedmont.

| Treatment Area | N | P | K | Ca | Mg |
|---|---|---|---|---|---|
| | | | ( % ) | | |
| Shear,rake,disk | 1.54 | 0.13 | 0.66 | 0.19 | 0.07 |
| Chop,burn | 1.50 | 0.14 | 0.77 | 0.16 | 0.07 |
| Shear-disk | 1.54 | 0.14 | 0.61 | 0.16 | 0.07 |

## SUMMARY

1. The highest levels of P in native vegetation, forest floor and surface soil were found in the plantation that had received the lowest intensity site preparation.

2. The lowest levels of P were found in the plantation that had received the intense burn.

3. Total pine biomass, trees per hectare, root collar diameter, height and volume index were greatest in the plantations that had received the most intensive site preparation.

4. No apparent P deficiency was present or imminent in any of the three plantations after three growing seasons.

## ACKNOWLEDGMENT

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EFFECTS OF SITE AMELIORATION ON GROWTH AND YIELD OF SLASH AND LOBLOLLY PINES PLANTED ON A CADDO SILT LOAM IN SOUTHWESTERN LOUISIANA[1/][2/]

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Abstract: Slash (*Pinus elliottii* Engelm. var. *elliottii*) and loblolly (*Pinus taeda* L.) pine seedlings were planted on a poorly drained Caddo silt loam in southwestern Louisiana in a completely randomized block design. The study area was sheared and burned, then plots were either harrowed, bedded, or left untreated. After 15 growing seasons, merchantable slash pines on the 2 mechanical treatments were significantly taller and had significantly greater average d.b.h. and inside bark (i.b.) and outside bark (o.b.) volumes per tree than those on checks. Means were also significantly different between the harrowed and bedded treatments for all four variables except total height. However, i.b. and o.b. volumes per hectare were not significantly different among treatments, and there were no significant differences in slash pine density among treatments. Merchantable 15-year-old loblolly pines did not differ significantly in mean d.b.h., height, and i.b. and o.b. volumes per tree or per hectare among the three treatments. By age 15, almost 60 percent of the slash pines and almost 50 percent of the loblolly pines were severely infected with fusiform rust, such that future stand potential was seriously reduced.

## INTRODUCTION

In this study, the growth and yield responses of slash (*Pinus elliottii* Engelm. var. *elliottii*) and loblolly (*Pinus taeda* L.) pines could be assessed on a poorly drained silt loam site that is free of pimple mounds. The 5-, 10-, and 15-year results are reported, and these addressed two objectives: (1) is growth and yield of slash and loblolly pines better on the two mechanically prepared plots than on checks and (2) are there differences between the two mechanical treatments? In addition, the severity of fusiform rust infection for both species greatly affected the results.

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## METHODS

The study area, located in southwestern Louisiana, had a uniform slope of 0 to 3 percent. The soil, a poorly drained Caddo silt loam (Typic Glossaqualfs, fine-silty, siliceous, thermic), had slow surface drainage and slow permeability with a perched water table at or near the surface in winter. In the early 1950's, longleaf pine (*Pinus palustris* Mill.) was established by direct seeding. The resulting stand of trees, 18 to 20 cm in d.b.h., was clearcut, and the residual woody vegetation was sheared in September 1969. Hardwood competitors were never again a significant percentage of stand basal area.

The 39- by 39-m research plots were burned in the winter of 1969-70. Burning was done to facilitate the planting of check plots and the installation of two mechanical treatments in September 1970: (1) harrowed--the plots were harrowed twice with an offset disk to reduce grass competition and (2) bedded--the plots were harrowed and then bedded with a bedding harrow that was equipped with a shaping roller. Beds were spaced 2.4 m apart; total bed height after settling averaged about 36 cm from furrow to crest.

In February 1971, either slash or loblolly pine seedlings (1-0) were planted at 256 planting spots per research plot. Planting locations were spaced about 2.4 by 2.4 m apart. To ensure adequate density, two seedlings were set by hand about 15 cm apart at each location. If both seedlings survived until October 1972, the least vigorous seedling was rogued. Measurement plots consisted of the central 100 planting locations on each research plot.

The study was initiated as a completely randomized block design with four blocks. The main treatment effects were pine species and site amelioration. However, data for each pine species were analyzed separately because their development on this site was radically different, and thus a formal statistical comparison was not worthwhile. The three treatments were contrasted by the following orthogonal trend comparisons: (1) check vs. the average for the two mechanical treatments and (2) harrowed vs. bedded ($p=0.05$).

On the 5-year-old slash and loblolly pine plots, mean height and pine density were reported. For the 10- and 15-year-old pines, mean d.b.h., height, inside bark (i.b.) and outside bark (o.b.) volume per tree, pine density, o.b. and i.b. volume per hectare, and basal area per hectare were measured and compared to determine if there were any treatment differences.

At age 5, total height to the nearest 3 cm was measured with a calibrated pole. At age 10, total height to the nearest 3 cm was measured with a calibrated pole, and d.b.h. was measured to the nearest 0.3 cm with calipers. Pines were classed as suppressed, intermediate, codominant, or dominant. The same features were measured at age 15, except heights were measured to the nearest 30 cm with an altimeter and d.b.h. was measured with a diameter tape.

Inside bark and o.b. individual tree volumes were calculated for slash pine with Lohrey's (1985) volume equations. Loblolly pine individual tree volumes were calculated with Hasness and Lenhart's (1972) volume equations. Pines less than 1.4 m tall were not included in the 10- and 15-year measurements because these trees could not be used in d.b.h. and volume estimates.

No fusiform rust (caused by *Cronartium quercuum* (Berk.) Miyabe and Shirai f. sp. *fusiforme* Burdsall and Snow) information was recorded at age 5, but fusiform rust galls were noted on some of the main stems at age 6; these data were used as rust data for the 5-year-old pines. At ages 10 and 15, presence of fusiform rust was noted if the pine had stem infections or the pine had become multistemmed (witches' brooms).

The percentage of 10- and 15-year-old slash and loblolly pines with fusiform rust infection are reported in two groups: (1) percentage of living pines with witches' brooms and (2) percentage of stem-infected pines among those without witches' brooms. However, the overall data are only for dominant and codominant pines classed as free of stem rust and for pines without witches' brooms, because any measurements of d.b.h. or volume estimates of trees with witches' brooms would be very inaccurate.

## RESULTS AND DISCUSSION

### Fusiform Rust

Fusiform rust infection was a serious problem for both species. By age 10, almost half the slash pine and one-third the loblolly pine were classed as having witches' brooms (table 1). There were no significant treatment differences for slash pine, but a significantly greater percentage of loblolly pines were seen with witches' brooms on harrowed and bedded plots than on checks. At age 15, the number of living trees with witches' brooms declined considerably for both species. Slash pine exhibited a greater percentage of witches' brooms on checks than on harrowed or bedded plots. However, there were no significant treatment differences for loblolly pine at age 15.

Fusiform rust infection generally increases over time and is often associated with the premature death of pines (Nance and others 1981). The rapid decline in the number of living trees with witches' brooms reflects this relationship, and, especially for slash pine, total stand mortality between ages 10 and 15 was largely associated with fusiform rust.

For slash pines without witches' brooms, the incidence of stem-rust was not significantly different among the three treatments at ages 5 and 10 (table 1). Rust infection averaged almost half for 5-year-old and about 40 percent for 10-year-old slash pines. For loblolly pines, rust infection averaged over 40 percent at age 5 and 34 percent at age 10.

However for 15-year-old slash pines without witches' brooms, there was a significantly greater incidence of stem-rust on bedded plots than on checks with intermediate results on the harrowed plots (table 1). The incidence of stem-rust among 15-year-old loblolly pines without witches' brooms was similar among the three treatments and averaged about 40 percent.

### Slash Pine Growth and Yield

Five-year-old slash pines were taller on the two mechanical treatments than on checks, but there was no difference in total height between the harrowed and bedded treatments (table 2). The same pattern of height response was noted for pines without witches' brooms at ages 10 and 15, and mean d.b.h. and o.b. and i.b. volumes per slash pine were significantly different among all three treatments. For slash pines without witches' brooms, volumes, basal area, and density per hectare values did not follow these patterns.

There were fewer slash pines per hectare at age 5 on the bedded plots than on the other two treatments (table 2). By age 10, there was a greater density of slash pines over 1.4 m tall on

Table 1.--The percentage of 10- and 15-year-old slash and loblolly pines with fusiform rust infection in two groups: percentage of living trees with witches' brooms and percentage of stem-infected trees among those without witches' brooms

| | Slash pine | | Loblolly pine | |
|---|---|---|---|---|
| | 10-year-data | 15-year-data | 10-year-data | 15-year-data |
| | Percentage of living pines with witches' brooms | | | |
| Check | 48.8a* | 17.6b | 25.7a | 6.4a |
| Harrow | 48.2a | 7.9a | 35.8b | 8.3a |
| Bed | 50.3a | 7.7a | 40.2b | 10.0a |
| Means | 49.1 | 11.1 | 33.9 | 8.2 |
| | Percentage of stem-infected pines among those without witches' brooms | | | |
| Check | 38.6a | 44.8a | 35.7a | 38.4a |
| Harrow | 35.2a | 51.7ab | 30.6a | 43.6a |
| Bed | 50.5a | 64.2b | 36.8a | 42.3a |
| Means | 41.4 | 53.6 | 34.4 | 41.4 |

* For each age, species, and group, column means followed by the same letter were not considered to be significantly different based on interpretation of the two orthogonal trend comparisons: (1) check vs. average for the two mechanical treatments and (2) harrowed vs. bedded (p=0.05).

Table 2.--Measurements of slash pine at three different ages on a Caddo silt loam flatwoods in southwestern Louisiana*

| Treatment | D.b.h. | Height | O.b. volume per tree | I.b. volume per tree | Pines per ha |
|---|---|---|---|---|---|
| | --cm-- | --m-- | -----------dm$^3$----------- | | -number- |
| 5 years | | | | | |
| Check | --** | 1.6a+ | -- | -- | 1,513b |
| Harrow | -- | 2.1b | -- | -- | 1,578b |
| Bed | -- | 2.4b | -- | -- | 1,333a |
| 10 years | | | | | |
| Check | 8.9a | 5.8a | 23.5a | 12.3a | 622ab |
| Harrow | 10.0b | 6.6b | 32.2b | 17.3b | 702b |
| Bed | 11.2c | 7.1b | 43.4c | 23.8c | 572a |
| 15 years | | | | | |
| Check | 14.2a | 9.4a | 92.8a | 55.5a | 702a++ |
| Harrow | 14.8b | 10.2b | 106.8b | 65.3b | 845a |
| Bed | 16.0c | 10.6b | 129.6c | 80.1c | 694a |
| MSE# | 0.357 | 0.467 | 139.0 | 63.3 | 28,065 |

* None of the measured trees showed evidence of witches' brooms.

** D.b.h. data were not collected, so volumes could not be calculated.

\+ For each age, column means followed by the same letter were not considered to be significantly different based on interpretation of the two orthogonal trend comparisons: (1) check vs. average for the two mechanical treatments and (2) harrowed vs. bedded (p=0.05).

++ Increase in stand density due to ingrowth by slash pine less than 1.4 m tall at age 10.

\# MSE = mean square error for 15-year data.

harrowed than on bedded plots with intermediate results for checks. At age 15, however, no significant differences in stand density were found among the check, harrowed, and bedded treatments. Also, basal area and volume per hectare results were not significantly different among 10- or 15-year-old slash pines. At age 15, slash pine averaged 13.9 $m^2$ of basal area, and 50.2 $m^3$ i.b. and 82.2 $m^3$ o.b. per hectare across all treatments.

Dominant and codominant pines free of stem-rust will be most of the future crop trees. At ages 10 and 15, dominant and codominant rust-free pines on the two mechanical treatments were taller on the average than pines on checks, but there was no significant difference between mechanical treatments (table 3). Pines on bedded plots had a greater mean d.b.h. and more volume per tree than those on checks with intermediate results on the harrowed plots.

There were more 10-year-old rust-free dominant and codominant slash pines per hectare on the harrowed treatment than on the bedded treatment with intermediate results on the check (table 3). However, by age 15, there were no significant differences in density among the check, harrowed, and bedded treatments.

At age 10, the best slash pines produced more i.b. volume per hectare on the harrowed plots than checks, with intermediate results on the bedded plots. But by age 15, these differences disappeared, when the average was 26.5 $m^3$ i.b. per hectare across all treatments. No significant treatment differences were found at either age for basal area or o.b. volume per hectare. The best 15-year-old slash pines averaged 7.0 $m^2$ of basal area and 42.8 $m^3$ o.b. per hectare across all treatments.

### Loblolly Pine Growth and Yield

For loblolly pines without witches' brooms, there were no significant differences in mean d.b.h., height, or volume per tree among the three treatments. The 15-year-old loblolly pines averaged 9.5 cm d.b.h., 6.1 m tall, 22.2 $dm^3$ i.b., and 32.6 $dm^3$ o.b. per tree across all treatments.

There were fewer 5-year-old loblolly pines per hectare on the bedded treatment than on the other two, but no significant differences in density were found for pines greater than 1.4 m tall at ages 10 and 15. The 15-year-old trees without witches' brooms averaged 820 per hectare on check, 824 per hectare on harrowed, and 647 per hectare on bedded plots. Furthermore, there were no significant differences in volume and basal area per hectare for either 10- or 15-year-old loblolly pines. Across all treatments, 15-year-old loblolly pines averaged 6.6 $m^2$ of basal area, 16.6 $m^3$ i.b., and 24.4 $m^3$ o.b. per hectare.

Among rust-free dominant and codominant 10- and 15-year-old loblolly pines there were no significant treatment differences. The 15-year-old loblolly pines averaged 12.6 cm d.b.h., 7.4 m tall, 36.9 $dm^3$ i.b., and 50.1 $dm^3$ o.b. per tree and 245 pines, 3.3 $m^2$ of basal area, 8.9 $m^3$ i.b., and 12.1 $m^3$ o.b. per hectare across all treatments.

## MANAGEMENT IMPLICATIONS

Bedding concentrates soil organic matter into planting ridges, which increases nutrient availability in the rooting zone of planted pines and raises the seedling's root system above standing water during rainy periods (Pritchett and Gooding 1975). On medium- to fine-textured soils, bedding improves aeration and increases the rate of water movement through the soil (Shoulders and Terry 1978). McKee and Shoulders (1970, 1974) determined that the growth benefits associated with bedding are correlated with the amount of added depth to free water provided by the beds if the average water table depth is less than 45 cm after winter rains. Thus, the bedding of poorly drained soils can result in better slash pine growth (Mann and McGilvray 1974). However, planting on beds is often not needed on somewhat poorly to moderately well-drained soils (Haywood 1980, 1983, Mann and McGilvray 1974, Tiarks 1983).

Based on per tree averages from the poorly drained site used in the present study, slash pines responded to site amelioration and grew best on the bedded plots. Among rust-free dominant and codominant slash pines, per tree averages were better on bedded plots than on checks, but there was no advantage to planting after harrowing, except for an increase in mean total height. However, there were no significant differences per hectare at age 15 for any of the variables tested, which suggests that site amelioration was ineffective. Still, one might decide to give more weight to the per tree results since these were small plots, fusiform rust greatly reduced stand density, and the per hectare values varied widely within treatments. For example, the respective mean square errors for 15-year-old slash pine were: basal area, 14.9 $(m^2/ha)^2$; i.b. volume, 255 $(m^3\ i.b./ha)^2$; and o.b. volume, 640 $(m^3\ o.b./ha)^2$.

On poorly drained soils, stands of loblolly pine often develop more slowly than those of slash pine (Shoulders 1976). However, young loblolly stands will often equal or surpass the growth and yield of slash pine stands on intermediate to dry sites (Haywood 1980, Haywood 1983, Shoulders 1976).

Loblolly pine seedlings were very severely damaged by tipmoth (*Rhyacionia* spp.), but damage was negligible among slash pine seedlings. This was believed to be the reason for the slow initial growth by loblolly pine. Since loblolly had been planted on other silt loam flatwoods without prolonged infestations by tipmoth, poor site quality might have predisposed this stand to attack.

Regardless, loblolly was about five growing seasons behind slash pine in diameter growth, height growth, and in volume production. Loblolly pine also did not respond to site amelioration. Clearly, loblolly pine was ill-suited for this poorly drained Caddo silt loam site. Limitations

Table 3.--Measurements of dominant and codominant slash pine free of stem-rust on a Caddo silt loam flatwoods in southwestern Louisiana

| Treatment | D.b.h. | Height | O.b. volume per tree | I.b. volume per tree | Pines per ha |
|---|---|---|---|---|---|
| | --cm-- | --m-- | -----------dm$^3$ | ----------- | -count- |
| 10 years | | | | | |
| Check | 10.2a* | 6.5a | 31.3a | 16.6a | 290ab |
| Harrow | 11.0ab | 7.1b | 39.4ab | 21.4ab | 357b |
| Bed | 11.9b | 7.6b | 49.9b | 27.7b | 219a |
| 15 years | | | | | |
| Check | 15.9a | 10.4a | 119.4a | 72.5a | 353a** |
| Harrow | 16.6ab | 11.3b | 139.0ab | 86.3ab | 353a |
| Bed | 17.9b | 11.8b | 165.6b | 103.6b | 235a |
| MSE+ | 0.686 | 0.282 | 281.0 | 122.0 | 8,800 |

* For each age, column means followed by the same letter were not considered to be significantly different based on interpretation of the two orthogonal trend comparisons: (1) check vs. average for the two mechanical treatments and (2) harrowed vs. bedded (p=0.05).

** Increase in number of pines classed as codominant or dominant due partly to ingrowth by trees that were less than 1.4 m tall at age 10.

\+ MSE = mean square error for 15-year data.

on phosphorus uptake and root development on wet soils might also partially explain these results (Burton 1971, Shoulders 1976, Tiarks and Shoulders 1982).

Fusiform rust greatly reduced the density of crop trees on this site. Still, the density of rust-free dominant and codominant slash pine was sufficient on the check and harrowed plots to continue the rotation (Powers, and others 1981). However, crop tree density on the bedded plots was marginal. Had the bedded plots been a commercial stand of slash pine, the best management option would have been to clearcut at age 15 and replant. Phosphorus fertilization would be an advisable option for the next rotation (Tiarks 1983).

For all treatments, the density of rust-free dominant and codominant loblolly pine was marginal (Powers, and others 1981). Had the loblolly pine treatments been commercial stands, the best management option would have been to clearcut at age 15, fertilize, and replant with slash pine.

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# RELATIVE PERFORMANCE OF LONGLEAF COMPARED TO LOBLOLLY AND SLASH PINES UNDER DIFFERENT LEVELS OF INTENSIVE CULTURE[1/]

R. C. Schmidtling[2/]

Abstract.--Longleaf, slash, and loblolly pines (Pinus palustris Mill., P. elliottii Engelm., and P. taeda L.) were grown under four levels of intensive culture. After 9 years, the treatments greatly increased growth of all three species with loblolly pines benefiting the most. Longleaf pines also benefited from intensive culture, but lagged far behind slash and loblolly in growth on all treatments after 9 years. After 25 years, 24 years after fertilizers were applied, the effects of intensive culture were still quite dramatic on all three species. The most important change was in relative performance of longleaf pines compared to slash and loblolly. Height of longleaf was equal to slash and greater than loblolly on control plots. Height of all three species was equal at the lowest levels of fertilizer. At the highest levels of fertilizers, loblolly was clearly superior in growth to longleaf and slash.

## INTRODUCTION

In the Southeastern United States, longleaf pine (Pinus palustris Mill.) forests may have occupied as much as 60 million acres before settlement (Wahlenburg 1964). Intensive exploitation since pioneer days and a lack of regeneration efforts have shrunk the once vast longleaf pine forests to less than 4 million acres today. Much of the remaining forests are natural second growth that, mostly by chance, sprang up following logging of the old-growth timber. Longleaf pine remains a commercially important timber tree throughout much of its natural range, with close to 60 percent of the standing volume found in Alabama, Florida, and Georgia (Sternitzke and Nelson 1970).

The majority of forest managers do not seriously consider longleaf pine in their management plans because of the slow early growth rates compared to slash (P. elliottii Engelm.) and loblolly (P. taeda L.) pines. However, many foresters believe that the long-term growth rate of longleaf is superior. Because of the high quality of longleaf pine, it is used for many forest products, and many landowners are taking advantage of recent improvements in longleaf regeneration techniques (Farrar and White 1983; Dennington and Farrar 1983) and growing longleaf pine today. In the present study, relative growth rates of longleaf, slash, and loblolly pines are compared in a 25-year-old intensive culture experiment.

## MATERIALS AND METHODS

The study area, about 25 miles north of Gulfport, Mississippi, had been stocked with second-growth longleaf pines before being clearcut in 1958-59. The soils are well-drained upland, fine sandy loams in the Poarch series and the Saucier-Susquehanna complex. Slope varies from 0 to 8 percent on the gently rolling land.

One-year-old seedlings of longleaf, slash, and loblolly pines were bar-planted at 10- by 10-foot spacings in February and March of 1960. The design was a split plot, randomized complete block with four replications. Each block consisted of 15 plots, 5 plots each of the 3 pine species. Each plot consisted of 100 trees (10 rows by 10 trees) surrounded by 2 rows of border trees. The total size of the plots, including border rows, was 0.52 acres. A different cultural treatment was applied

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to each of the five plots of each species. The treatments are listed in table 1.

Table 1.--Treatments and abbreviations

| Abbreviation | Treatment |
|---|---|
| C | Control, no cultivation or fertilizer; |
| F-0 | Cultivated, but not fertilized; |
| F-1 | Cultivated, with a single application of 100 lbs N, 21 lbs P, and 42 lbs K per acre; |
| F-2 | Cultivated, with a single application of 200 lbs N, 42 lbs P, and 84 lbs K per acre; |
| F-4 | Cultivated, with a single application of 400 lbs N, 85 lbs P, and 167 lbs K per acre. |

Stumps, soil, and competing vegetation were not disturbed on control plots. Cultivated plots were cleared of all stumps and slash, then plowed, disked, and planted. Cultivation consisted of disking three times each season for 3 years after planting and mowing in years 4 and 5. Fertilizer was applied with an agricultural spreader and disked into the soil in May 1961, 1 year after planting.

Heights of all trees were measured at ages 1, 2, 3, 4, 5, 6, 9, and 25. In addition, heights were measured at age 12 for the slash and at age 17 for the loblolly. D.b.h. was measured on all trees at ages 6, 9, and 25.

Linear regressions were fitted to 1/age-log height transformations for all species/treatment combinations using dominant-codominant heights (the tallest 100 trees per acre) and available data for ages 4 through 25. These regression were then used to construct site-index curves.

Species means were compared by analyses of variance. Differences within treatments are of interest, but differences in most measured characters are significant because of the large response to intensive culture. For most measured characters, the interaction between species and cultural treatment was significant; therefore each treatment was analyzed separately for species effects. Statistical significance was tested at 0.05 level of probability.

## RESULTS AND DISCUSSION

The relative growth rates and the shape of the height/age curves of the three species varied considerably according to cultural treatment (fig. 1). At age 9, the growth of loblolly was clearly superior to slash, which was in turn superior to longleaf. After age 9, the growth of loblolly was considerably slower than slash and longleaf on C and F-0 plots. Average height of loblolly on C plots was only 41.1 feet at 25 years compared to 47.7 feet for slash and 51.9 for longleaf (table 2). The changes in rank among species on the F-0 plots was similar to that which occurred on the C plots (fig. 1).

As the intensity of culture increased, the relative growth rate of loblolly accelerated (fig. 1); at age 25 the loblolly averaged 7 feet taller than the slash or longleaf on plots that had received the highest rates of fertilization (table 2).

The longleaf pine, although starting out slower than the other species, equaled the growth of slash pine and exceeded the growth of loblolly at lower levels of intensive culture by the 25th year.

Survival of longleaf was low on C plots due to severe competition. Fewer than 30 percent of the longleaf survived at 25 years on control plots compared to 50 percent of the loblolly and 70 percent of the slash (fig. 2). Survival of longleaf on F-0 plots was as good or better than survival of slash and loblolly: Longleaf and slash averaged 60 percent survival compared to 44 percent for loblolly. Survival of the longleaf on the fertilized plots averaged slightly higher than slash or loblolly (fig. 2). The necesssity of early competition control for survival of longleaf seedlings was clearly evident in this study.

The method of competition control, i.e., cultivation two or three times a year for the first 3 years does not appear to be desirable, however. The average height of longleaf was lower on F-0 plots than on C plots, 46.5 feet versus 51.9 feet respectively (table 1). A study of soil chemistry in this planting at age 23 (fig. 3) showed that cultivation alone reduced organic matter and micro-nutrients (such as copper), and the soil on longleaf plots was affected much more than soil on loblolly plots. After 23 years, or 20 years after cultivation ceased, organic matter content was only 1.1 percent on F-0 plots compared to an average of 1.6 percent on the other plots. The nutrients mobilized by oxidation of the organic matter during cultivation could not be captured and recycled by the slow growing longleaf, resulting in loss of nutrients in the soil and poorer growth. The use of herbicides in this study would likely have resulted in significantly less long-term environmental damage.

Basal area of longleaf is comparable to slash and loblolly on all plots except the controls (fig. 2). Longleaf averaged greater in d.b.h. than slash or loblolly on C plots (table 1), but survival was so much lower that the longleaf averaged only 32 $ft^2$ basal area per acre compared to 42 $ft^2$/acre for loblolly and 55 $ft^2$/acre for slash pine. Basal area on F-1 and F-2 treatments was equal for the three species. Longleaf basal area on F-0 and F-4 plots was intermediate to slash and loblolly.

Table 2.--Average height and d.b.h. at 25 years for longleaf, slash, and loblolly pines under different levels of intensive culture

| Species | Treatment[1/] | | | | |
|---|---|---|---|---|---|
| | C | F-0 | F-1 | F-2 | F-4 |
| | Height (feet) | | | | |
| Longleaf | 51.9*[2/] | 46.5* | 58.1 | 60.1 | 59.4* |
| Loblolly | 41.1* | 42.7* | 58.6 | 61.0 | 67.3* |
| Slash | 47.7* | 51.5* | 59.0 | 62.0 | 60.0* |
| | d.b.h. (inches) | | | | |
| Longleaf | 7.00* | 6.07 | 8.02 | 8.65 | 8.59* |
| Loblolly | 6.05* | 6.26 | 8.81 | 9.30 | 9.94* |
| Slash | 6.40* | 6.91 | 8.36 | 8.82 | 9.00* |

1/See table 1 for treatment.

2/Significant differences within columns at 0.05 are indicated by an asterisk.

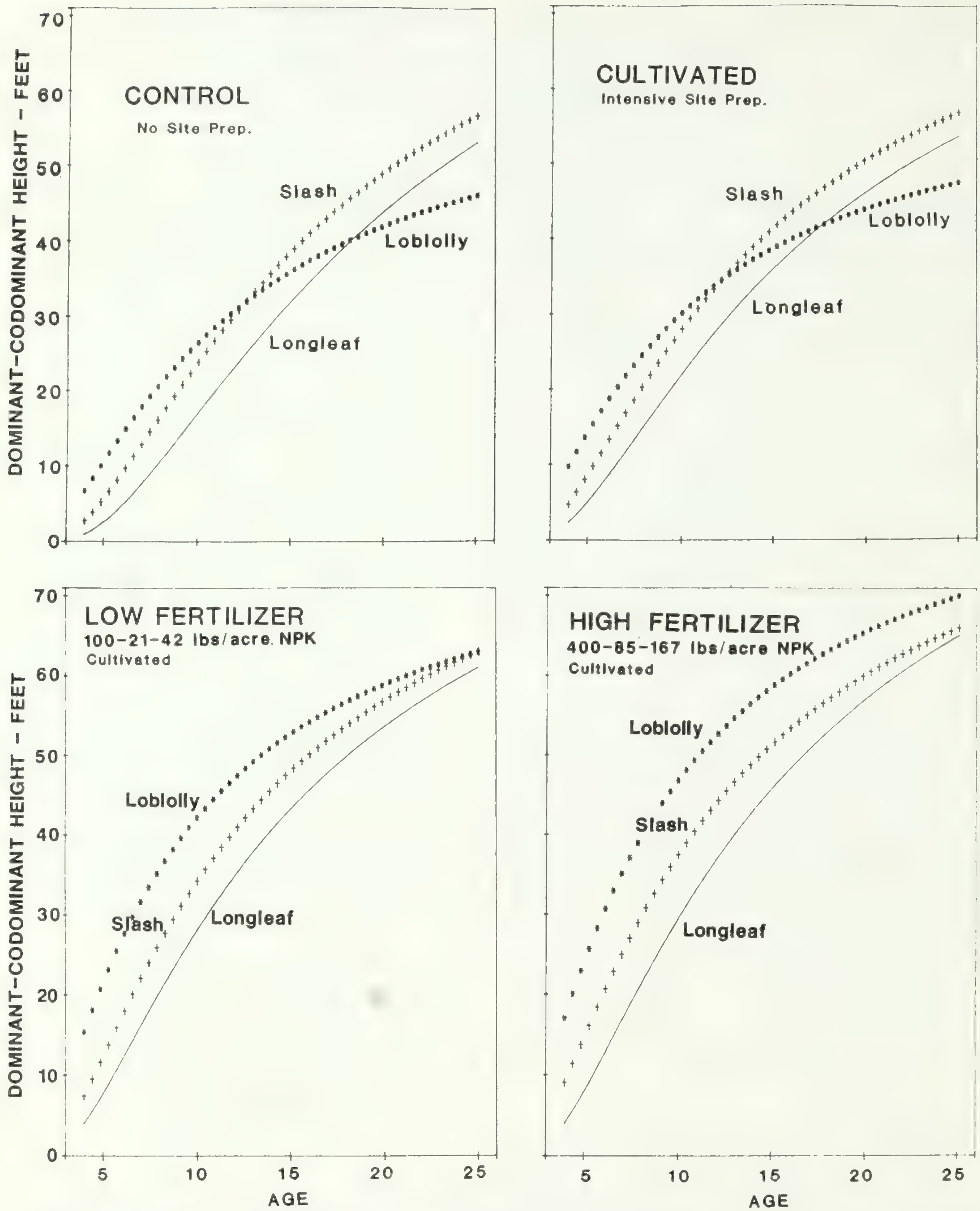


Figure 1.--Height versus age curves for three southern pine species under different cultural treatments. Curves are derived from linear regressions of log height-1/age transformations. Medium fertilizer (F-2) is not shown for simplicity.

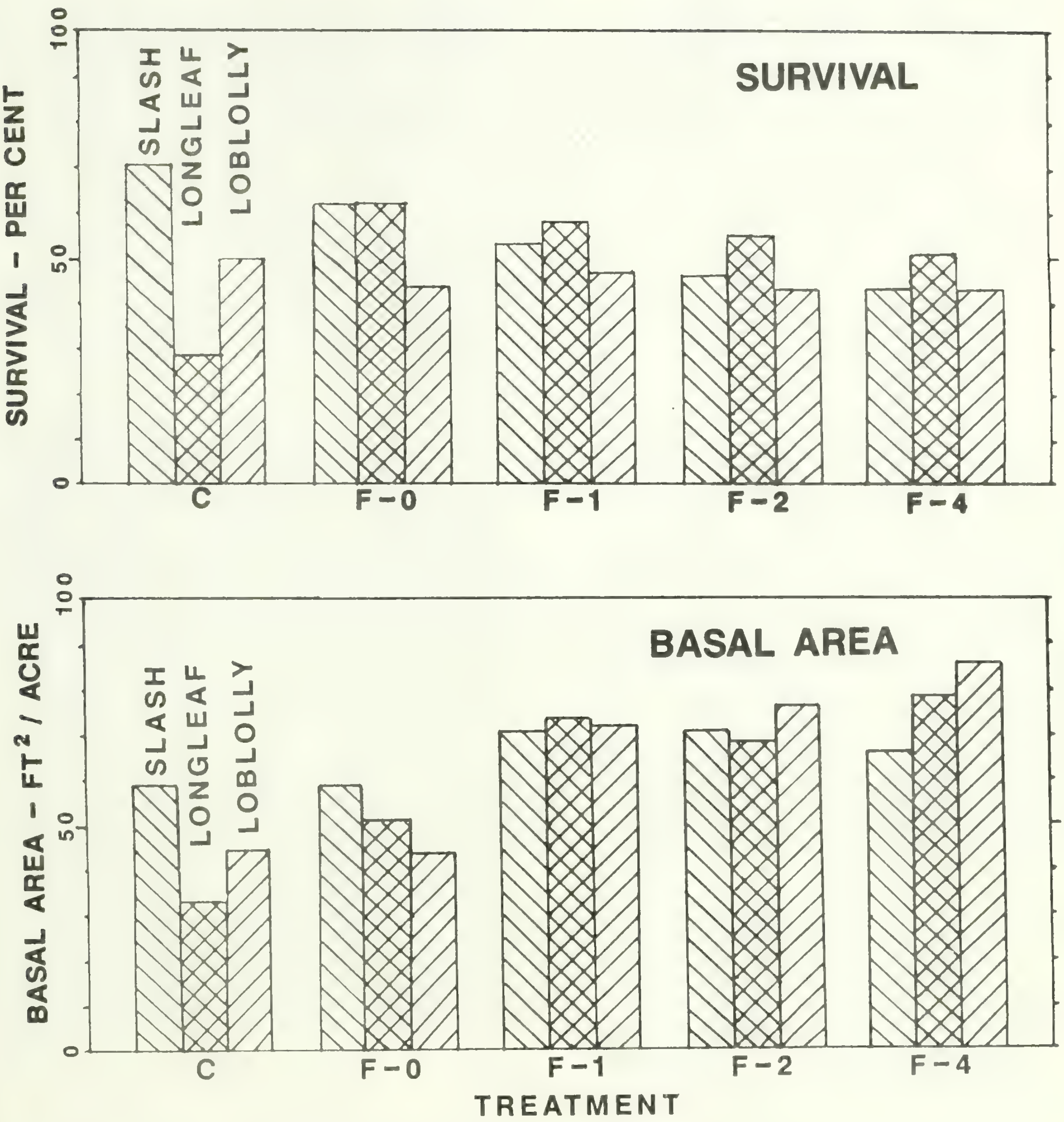


Figure 2.--25 year survival and basal area for three southern pine species under five different cultural treatments. See table 1 for explanation of treatments.

## CONCLUSIONS

The range of treatments in this experiment actually simulated a range of site quality from poor to average. The growth of longleaf was as good as slash and loblolly under most conditions. Longleaf would appear to be more a desirable species to plant because it is naturally resistant to fusiform rust and southern pine beetles. Longleaf also generally yields higher-valued forest products. Recent advances in planting techniques, competition control, and brown-spot suppression by chemical or genetic manipulation will hopefully lead to a revival of interest in regeneration and managing longleaf pines.

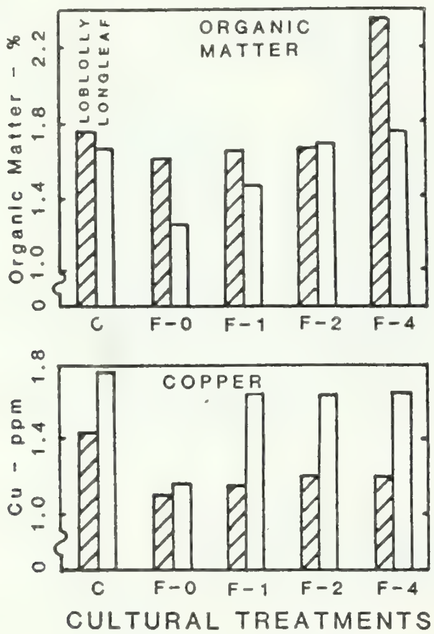


Figure 3.--Effects of cultivation and fertilization on organic matter and copper content of soils 24 years after treatment (Schmidtling 1985). See table 1 for explanation of treatments.

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COMPACTION ALTERS SOIL PHYSICAL PROPERTIES AND ROOT GROWTH OF INOCULATED AND NONINOCULATED YELLOW-POPLAR AND SWEETGUM SEEDLINGS[1/]

G. L. Simmons and P. E. Pope[2/]

Abstract.--Soils at two field sites were subjected to increasing compaction and changes in soil physical properties and root responses of inoculated and noninoculated yellow-poplar (Liriodendron tulipifera L.) and sweetgum (Liquidambar syraciflua L.) seedlings were determined. Seedlings were inoculated in the nursery with a sterilized (control) inoculum or with inoculum containing the mycorrhizal fungi Glomus macrocarpum or G. fasciculatum. Two compaction treatments and a noncompacted control were established at each site and 1-0 seedlings were grown for one year. Surface bulk densities increased and total and air-filled porosities decreased with increasing compaction at each site. Mycorrhizal treatments did not significantly affect root growth at either site. After one year, roots of seedlings from all treatments were mycorrhizal. At both sites, root length and weight of sweetgum were greater than yellow-poplar on all compaction treatments. Root responses were greater at Site 1 due to lower bulk densities and a higher soil moisture content. With the exception of sweetgum at Site 1, root growth decreased significantly as surface bulk density increased above 1.30 Mg $m^{-3}$.

## INTRODUCTION

A reduction in potential productivity of forest soils resulting from compaction is of major concern to foresters and land managers. A reduction in the growth rate of trees in compacted soils has been reported for Virginia pine (Kreh et al. 1984), loblolly pine (Lockaby and Vidrine 1984; Mitchell et al. 1982; Simmons and Ezell 1982; Hatchell et al. 1970), ponderosa pine (Froelich 1979), radiata pine (Sands et al. 1979) and Douglas-fir (Wert and Thomas 1981). The reduced growth rates are usually attributed to changes in soil physical properties, primarily increased bulk density and strength and reduced soil aeration.

The survival of transplanted seedlings depends largely on root penetration and exploration of the soil profile. Because of the complexity of root studies, relationships between root growth and soil compaction have not been studied extensively. The extent to which growth is reduced and the soil conditions which limit root growth have not been well-defined. Two objectives of this study were to characterize changes in soil physical properties associated with increases in compaction and to determine if root growth of 1-0 yellow-poplar and sweetgum seedlings is affected by changes in these soil properties.

High quality nursery stock may be a means of increasing site productivity. Recent work has demonstrated that the quality of some species of hardwood seedlings produced in the nursery is improved by endomycorrhizal colonization of the root systems (Bryan and Kormanik 1977; Kormanik et al. 1982; South 1977; Schultz et al. 1981). Species of hardwoods which show a significant growth response when inoculated with endomycorrhizal fungi following soil sterilization or fumigation include sweetgum (Gray and Gerdemann 1967; Kormanik et al. 1977), yellow-poplar (Clark 1963; Gray and Gerdemann 1967), sycamore (Pope 1980), and white ash (Pope and Holt 1981). Currently, there are no studies which examine the field performance of inoculated seedlings grown in compacted soils. The third objective of this study was to determine the influence of the endomycorrhizal fungi Glomus macrocarpum or G. fasciculatum on the root growth of yellow-poplar and sweetgum seedlings inoculated in the nursery and grown in compacted soils.

## MATERIALS AND METHODS

### Selection of Experimental Materials

Yellow-poplar and sweetgum were selected primarily because of morphological differences in the root characteristics of the two species. Typically, sweetgum has a very fine and highly branched (fibrous) root system; yellow-poplar roots are comparatively coarse and less branched. The Glomus species (G. macrocarpum and G. fasciculatum) were chosen because results of an earlier study indicated that both yellow-poplar and sweetgum demonstrated a high mycorrhizal dependency for these two fungal species (Pope et al. 1983).

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## Seedling Preparation

Yellow-poplar and sweetgum seed were sown at Vallonia State Nursery, Vallonia, IN in May, 1984. Seedbeds were inoculated one month later with mixed pot culture inoculum of G. macrocarpum or G. fasciculatum or sterilized pot culture soil. Inoculum consisting of soil, spores, and chopped roots of petunia, was incorporated into the seedbed between the rows of newly germinated seedlings to a depth of 5 cm (described by Menge and Timmer 1982) at a concentration of approximately 21,500 spores $m^{-2}$. Seedbeds were thinned to 108 seedlings $m^{-2}$ (10 seedlings $ft^{-2}$) in July, 1984. Seedlings were watered and fertilized under standard nursery practices. In November, 1984, seedlings were undercut at a depth of 20 cm, mechanically lifted, and placed in cold storage at 4°C. Lateral roots (< 5 mm diam) of ten seedlings from each mycorrhizal treatment were cleared with KOH and stained with trypan blue (Phillips and Hayman 1970). Fifty root segments (1 cm) from each sampled seedling were evaluated for mycorrhizal colonization using the slide method described by Kormanik and McGraw (1982).

## Site Location and Establishment

Site 1, located in Dubois County, IN, was classified as an old field in early stage succession. The soil was a well-drained, eroded phase of a Zanesville silt loam (Typic Fragiudalf - fine silty, mixed mesic), which occurs extensively in the nonglaciated southern portion of the state. Site 2, classified as a marginal farmland site, was located in Tippecanoe County, IN. The soil was a somewhat poorly drained Fincastle silt loam (Aeric Ochraqualf - fine silty, mixed mesic), which occurs throughout the glaciated portion of the state.

Weather stations were established near each site and monthly precipitation and evaporation data were collected for the duration of the study. Available water during the growing season was calculated for each site based on these weather station data and moisture retention analyses.

The sites were cleared of brush and woody vegetation (Site 1) or cornstalks (Site 2), and disked in November, 1984. Compactibility of each soil was determined by applying surface pressures of 104, 242, and 380 kPa to samples with increasing moisture content and calculating the resulting bulk densities (Felt 1965).

A vibratory roller (380 kPa surface pressure) was used to apply two compaction treatments at each site in April, 1985. Different surface bulk densities were attained by varying the speed and vibration of the roller and the moisture content of the soil at the time that the treatments were applied. The desired surface bulk densities of Compaction Level 1 (CL1) and Compaction Level 2 (CL2) were representative of medium and highly compacted conditions for the respective soils, based on compactibility data. A noncompacted area in each replication served as an undisturbed control (CON).

Sites were fertilized in April, 1985 in a broadcast application to adjust the available nutrient content to 140 kg $ha^{-1}$ nitrogen ($NH_4NO_3$), 84 kg $ha^{-1}$ phosphorus (superphosphate), and 336 kg $ha^{-1}$ potassium (potash). Chemical weed control (1.6 L glyphosate, 1 L diquat, 4.48 kg oryzalin, and 1.12 kg simazine $ha^{-1}$) was applied prior to planting and each site was treated as needed to minimize root growth of weeds in the plots. Seedlings were hand planted at each site in April, 1985.

## Measurements

Soil medium from the upper 20 cm was used to determine particle size distribution of each soil. A Uhland core sampler was used to collect soil core samples from each compaction treatment at 0-7.6, 7.6-15.2, 15.2-22.9, and 22.9-30.5 cm depths. Bulk density, soil strength, water retention at -10 -60 , and -100 kPa, available water holding capacity, and total and air-filled porosity were determined at each depth for each compaction treatment. Methods are described in Methods of Soil Analysis (Black 1965).

Height and basal diameter were measured in May, 1985 and October, 1985. Based on these stem data, average seedlings from each compaction/mycorrhizae treatment were selected for possible root examination. One randomly selected seedling of each species was excavated by hand from each compaction treatment (six seedlings/site) to determine horizontal and vertical extent of root growth. In addition, one seedling of each species was randomly selected from each compaction/mycorrhizae treatment (18 seedlings/site) for core sampling.

A hydraulic probe was used to collect soil core samples. Based on root distribution of the excavated seedlings, cores were taken from radii of 22.9, 45.7, and 68.6 cm around each selected seedling. Four cores were taken at each radius to a depth of 38.1 cm. Each core was then divided into sections by depth (0-7.6, 7.6-15.2, 15.2-22.9, 22.9-30.5, 30.5-38.1) and cores from the same depth were combined for each radius. The hydropneumatic elutriation method of Smucker et al. (1982) was used to separate and collect roots from soil cores, and root weight, length, and distribution were determined. Root subsamples were evaluated for mycorrhizal colonization as previously described.

## Experimental Design

The study was established as a randomized complete block with treatments arranged in a split plot design (three compaction treatments, two tree species, three mycorrhizal treatments). Each site had three replications and 16 seedlings in each compaction/mycorrhizae treatment plot. Stem data were analyzed by analysis of variance. Root data were pooled for mycorrhizal treatments and analyzed by analysis of variance and analysis

of covariance, using original stem height and root collar diameter as covariates. Ranked means were analyzed by Duncan's multiple range test.

## RESULTS AND DISCUSSION

### Soil Physical Properties

Although soils at both sites were classified as silt loams, soil from the upper 20 cm at Site 1 had a higher proportion of sand and clay size particles (15 percent sand, 68 percent silt, 17 percent clay) than Site 2 soil (5 percent sand, 83 percent silt, 12 percent clay), and consequently, was more compactible (Fig. 1).

When soil from Site 1 was subjected to 104 kPa surface pressure, bulk density increased from 1.30 Mg $m^{-3}$ at a soil moisture content of 15 percent to 1.42 Mg $m^{-3}$ at a moisture content of 30 percent (Fig. 1). Similarly, bulk densities increased to 1.49 and 1.53 Mg $m^{-3}$ when samples were subjected to surface pressures of 242 and 380 kPa, respectively. The soil moisture content where maximum bulk densities were obtained with these pressures was approximately 25 percent.

Bulk densities of soil samples from Site 2 increased from 1.39 to 1.60 Mg $m^{-3}$ at a moisture content of 23 percent when subjected to a ground pressure of 104 kPa (Fig. 1). When 242 and 380 kPa ground pressures were used, maximum bulk densities of 1.69 and 1.74 Mg $m^{-3}$, respectively, were obtained at a moisture content of approximately 19 percent.

The surface (0-7.6 cm) bulk density of the noncompacted CON at Site 1 was approximately 1.15 Mg $m^{-3}$ (Fig. 2). At the 7.6-15.2 and 15.2-22.9 cm depths, bulk density increased to 1.33 and 1.40 Mg $m^{-3}$, respectively. Based on compactibility data, the desired surface bulk densities were 1.30 and 1.50 Mg $m^{-3}$ for CL1 and CL2, respectively. Average surface bulk densities attained were 1.30 Mg $m^{-3}$ for CL1 and 1.35 Mg $m^{-3}$ for CL2. At depths exceeding 7.6 cm, bulk densities were not significantly increased for either compaction treatment. The soil moisture content was approximately 15 percent when CL1 was applied and 25 percent when CL2 was applied. However, surface bulk densities attained were lower than anticipated, based on compactibility data.

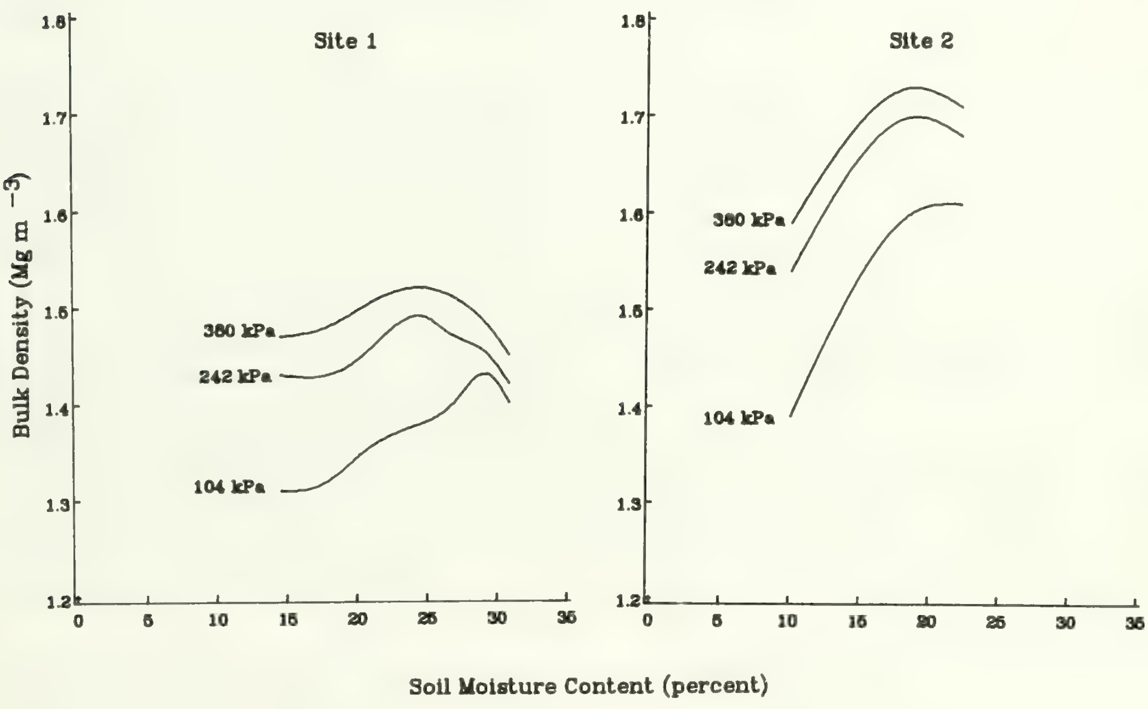


Figure 1.--Bulk densities obtained for soil samples (0-20 cm) from Site 1 and Site 2 subjected to ground pressures of 104, 242, and 380 kPa at soil moisture contents ranging from 10 to 35 percent.

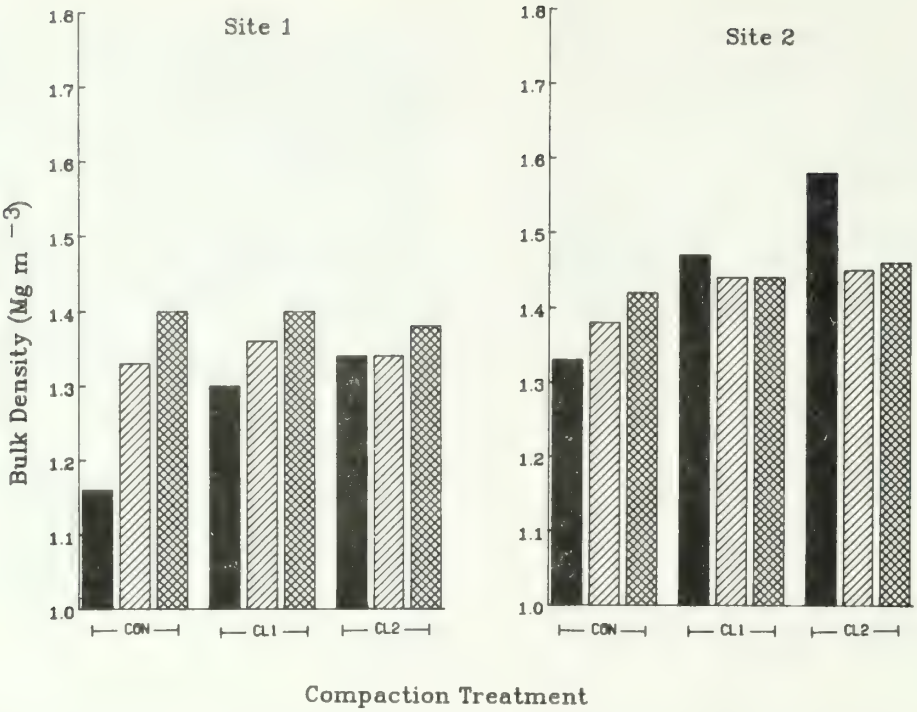


Figure 2.--Average bulk density for Control (CON), Compaction Level 1 (CL1), and Compaction Level 2 (CL2) treatments at 0-7.6 cm, 7.6-15.2 cm, and 15.2-22.9 cm depths at Site 1 and Site 2.

The noncompacted (CON) surface bulk density at Site 2 was 1.33 Mg $m^{-3}$, and increased to 1.38 Mg $m^{-3}$ at 7.6-15.2 cm, and 1.43 Mg $m^{-3}$ at 15.2-22.9 cm depths (Fig. 2). To enable comparison of seedling root responses between sites, the desired surface bulk densities for CL1 and CL2 were 1.45 and 1.55 Mg $m^{-3}$, respectively, although this soil was more compactible than Site 1 soil. Average surface bulk densities attained for CL1 and CL2 were 1.47 and 1.58 Mg $m^{-3}$, at soil moisture contents of 10 and 20 percent, respectively. At depths exceeding 7.6 cm the bulk density was approximately 1.43 Mg $m^{-3}$ for both compaction treatments.

Total and air-filled porosity decreased linearly with increasing bulk density at each site. Total porosity decreased from approximately 57 percent on the CON (bulk density = 1.15 Mg $m^{-3}$) to 51 percent at CL1 (bulk density = 1.30 Mg $m^{-3}$) and 50 percent at CL2 (bulk density = 1.35 Mg $m^{-3}$) on Site 1 (Fig. 3). Air-filled porosity decreased from 18 percent for noncompacted soils to 12 percent at the highest compaction level on Site 1 when soil moisture potential was maintained near field capacity (-10 kPa). At Site 2, total porosity decreased from approximately 50 percent on the CON (bulk density = 1.33 Mg $m^{-3}$) to 45 percent at CL2 (bulk density = 1.58 Mg $m^{-3}$) (Fig. 3). Air-filled porosity decreased from 15 percent on the CON to 5 percent at CL2 when soil moisture potential was -10 kPa. Air-filled porosity at soil moisture potentials of -60 and -100 kPa decreased similarly at each site.

Based on water retention analyses, the total available water holding capacity for both sites was approximately 0.12 cm $cm^{-1}$ (Fig. 4). However, because of low amounts of precipitation at Site 2 (June-October), the actual available water at this site was lower than at Site 1, and a water deficit existed during much of the growing season at this site.

Seedling Root Responses

Approximately 30 percent of yellow-poplar and sweetgum lateral roots sampled were colonized by G. macrocarpum or G. fasciculatum when inoculated seedlings were lifted from nursery seedbeds. Roots of noninoculated seedlings were not colonized at this time. However, at the end of the first growing season, mycorrhizal colonization did not differ significantly for inoculated and noninoculated seedlings at either site. Consequently, root growth was not significantly influenced by mycorrhizal treatment.

At Site 1, length and weight of yellow-poplar roots decreased significantly as compaction increased from CL1 to CL2 or as surface bulk density increased above 1.30 Mg $m^{-3}$ (Table 1). Length and weight of sweetgum roots varied. At Site 2, root length and weight of both species decreased significantly as compaction increased from CON to CL1 or as surface bulk density increased from 1.33 to 1.47 Mg $m^{-3}$.

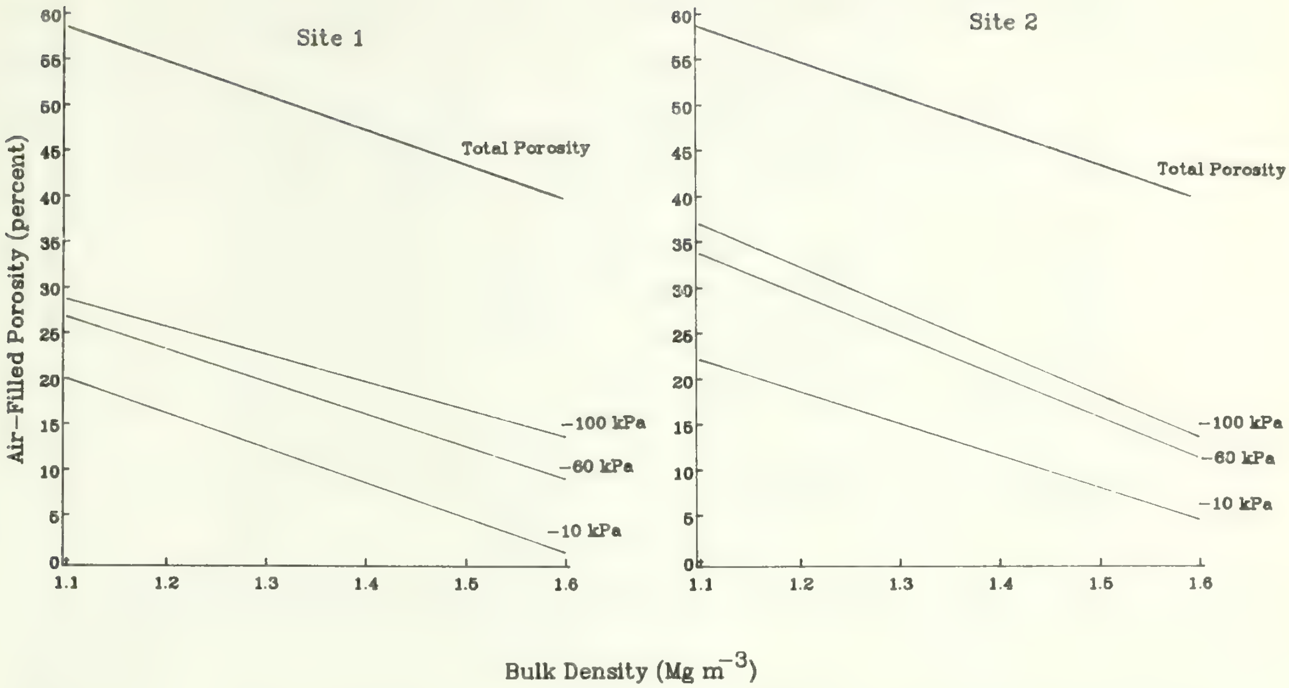


Figure 3.--Total porosity and air-filled porosity at -10 -60 and -100 kPa at bulk densities ranging from 1.1 to 1.6 Mg $m^{-3}$ for Site 1 and Site 2 soil.

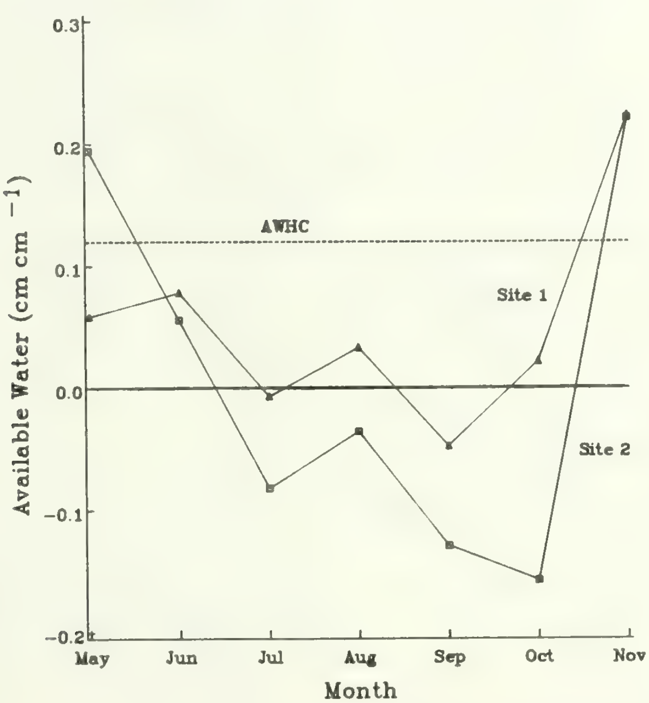


Figure 4.--Available water holding capacity (AWHC) and available water at Site 1 and Site 2 for May-November, 1985.

Table 1.--Length and oven-dry weight of cored yellow-poplar and sweetgum roots on Control (CON), Compaction Level 1 (CL1), and Compaction Level 2 (CL2) at Site 1 and Site 2.

| | Site 1 | | | Site 2 | | |
|---|---|---|---|---|---|---|
| | CON | CL1 | CL2 | CON | CL1 | CL2 |
| Yellow-Poplar | | | | | | |
| Length (cm) | 495a[a] | 491a | 95b | 193a | 63b | 2b |
| Weight (g) | 1.15a | 1.39a | 0.30b | 0.58a | 0.14b | 0.01c |
| Sweetgum | | | | | | |
| Length (cm) | 663a | 112b | 887a | 533a | 82b | 178ab |
| Weight (g) | 0.82b | 0.12b | 2.42a | 2.18a | 0.19b | 0.39b |

[a]Row values for each site followed by different letters are significantly different at P = 0.01.

Although trends were similar for both species at Site 2, root length and weight of sweetgum were greater than yellow-poplar on each compaction treatment. These differences in species may be attributable to differences in morphology of the root systems. The fibrous lateral roots of sweetgum were able to penetrate more extensively into the soil profile than the coarse lateral roots characteristic of yellow-poplar.

Horizontal root extension, as determined by length and weight of roots occurring in soil cores taken at each radius and totalled for all depths, was affected similarly by compaction. At Site 1, yellow-poplar roots extended laterally to 68.6 cm on the CON and CL1, but extension was restricted to a radius of 45.7 cm on CL2 (Table 2).

Horizontal growth of sweetgum roots varied, with greatest lateral extension occurring on CL2. At Site 2, no roots of either species extended laterally past a radius of 45.7 cm (Table 3). Roots of both species were restricted to 22.9 cm or less on CL1 and CL2 treatments.

At Site 1, vertical extension of yellow-poplar roots, as determined by length and weight of roots occurring in soil cores taken at each depth and totalled for all radii, decreased significantly as compaction increased from CL1 to CL2 for depths to 22.9 cm (Table 4). Although no significant differences occurred below this depth, roots were absent from the 30.5-38.1 cm depth on CL2. Vertical extension of sweetgum roots varied at this site.

At Site 2, roots of both species were absent or extremely limited in the surface (0-7.6 cm) cores for all treatments (Table 5). For both species, root length and weight at the 7.6-30.5 cm depths decreased significantly as compaction increased from CON to CL1.

Differences in root responses between sites were due primarily to differences in soil moisture content. Because a water deficit existed at Site 2 for much of the growing season, seedlings were subjected to water stress. In addition, drier soil conditions and higher bulk densities at Site 2 resulted in greater soil strength, although this property was variable at each site.

At Site 1, horizontal extension of yellow-poplar roots within the surface layer was probably limited by increased soil strength associated with higher bulk densities on CL2. At Site 2, root growth near the surface was limited by dry soil conditions on all treatments. At higher compaction levels, roots were further limited by a combination of increased bulk density and strength.

Although compaction did not significantly increase bulk densities at depths exceeding 7.6 cm, vertical root extension was influenced by compaction at depths to 38.1 cm. This could have been due to reduced air-filled porosity of the compacted surface layer, which would have decreased $O_2$ and $CO_2$ diffusion rates to and from the roots at lower depths.

## SUMMARY

With the exception of sweetgum at Site 1, seedling root responses at both sites were similar: increasing surface bulk densities above approximately 1.30 Mg $m^{-3}$ resulted in reduced growth and limited distribution, and mycorrhizal inoculation had no effect on responses. Generally, total root length and weight were greater and distribution was more extensive for sweetgum seedlings, due to the fibrosity of the root system.

Table 2.--Length and oven-dry weight of cored yellow-poplar and sweetgum roots by radius (totalled for all depths) for Control (CON), Compaction Level 1 (CL1), and Compaction Level 2 (CL2) at Site 1.

| Radius (cm) | CON Length (cm) | CON Weight (g) | CL1 Length (cm) | CL1 Weight (g) | CL2 Length (cm) | CL2 Weight (g) |
|---|---|---|---|---|---|---|
| | | | Yellow-Poplar | | | |
| 22.9 | 353a[a] | 0.74a | 330a | 0.92a | 72b | 0.21b |
| 45.7 | 122a | 0.36a | 142a | 0.34ab | 23b | 0.08b |
| 68.6 | 20a | 0.05a | 20a | 0.13a | 0b | 0.00b |
| | | | Sweetgum | | | |
| 22.9 | 492ab | 0.62ab | 95b | 0.10b | 680a | 2.10a |
| 45.7 | 172a | 0.20a | 17a | 0.02a | 125a | 0.26a |
| 68.6 | 0b | 0.00b | 0b | 0.00b | 82a | 0.06a |

[a]Row values for each root parameter followed by different letters are significantly different at P = 0.01.

Table 3.--Length and oven-dry weight of cored yellow-poplar and sweetgum roots by radius (totalled for all depths) for Control (CON), Compaction Level 1 (CL1), and Compaction Level 2 (CL2) at Site 2.

| Radius (cm) | CON Length (cm) | CON Weight (g) | CL1 Length (cm) | CL1 Weight (g) | CL2 Length (cm) | CL2 Weight (g) |
|---|---|---|---|---|---|---|
| | | | Yellow-Poplar | | | |
| 22.9 | 162a[a] | 0.53a | 63b | 0.14b | 2c | 0.01c |
| 45.7 | 32a | 0.05a | 0b | 0.00a | 0b | 0.00a |
| 68.6 | 0a | 0.00a | 0a | 0.00a | 0a | 0.00a |
| | | | Sweetgum | | | |
| 22.9 | 520a | 2.16a | 82b | 0.09b | 178ab | 0.39b |
| 45.7 | 13a | 0.20a | 0b | 0.00b | 0b | 0.00b |
| 68.6 | 0a | 0.00a | 0a | 0.00a | 0a | 0.00a |

[a]Row values for each root parameter followed by different letters are significantly different at P = 0.01.

Table 4.--Length and oven-dry weight of cored yellow-poplar and sweetgum roots by depth (totalled for all radii) for Control (CON), Compaction Level 1 (CL1), and Compaction Level 2 (CL2) at Site 1.

| Depth (cm) | CON Length (cm) | CON Weight (g) | CL1 Length (cm) | CL1 Weight (g) | CL2 Length (cm) | CL2 Weight (g) |
|---|---|---|---|---|---|---|
| | | | Yellow-Poplar | | | |
| 0-7.6 | 157a[a] | 0.44a | 25ab | 0.06b | 0b | 0.00b |
| 7.6-15.2 | 230a | 0.20ab | 135ab | 0.45a | 20b | 0.07b |
| 15.2-22.9 | 82ab | 0.27a | 140a | 0.31a | 48b | 0.14a |
| 22.9-30.5 | 77a | 0.15a | 100a | 0.34a | 27a | 0.08a |
| 30.5-38.1 | 40a | 0.09a | 92a | 0.24a | 0a | 0.00a |
| | | | Sweetgum | | | |
| 0-7.6 | 327a | 0.40ab | 35b | 0.03b | 218ab | 0.74a |
| 7.6-15.2 | 188a | 0.25b | 53b | 0.05b | 264a | 0.85a |
| 15.2-22.9 | 70ab | 0.07b | 10b | 0.02b | 187a | 0.35a |
| 22.9-30.5 | 53a | 0.09a | 13a | 0.02a | 106a | 0.24a |
| 30.5-38.1 | 25a | 0.01a | 0a | 0.00a | 103a | 0.24a |

[a]Row values for each root parameter followed by different letters are significantly different at P = 0.01.

Table 5.--Length and oven-dry weight of cored yellow-poplar and sweetgum roots by depth (totalled for all radii) for Control (CON), Compaction Level 1 (CL1), and Compaction Level 2 (CL2) at Site 2.

| Depth (cm) | CON Length (cm) | CON Weight (g) | CL1 Length (cm) | CL1 Weight (g) | CL2 Length (cm) | CL2 Weight (g) |
|---|---|---|---|---|---|---|
| | | | Yellow-Poplar | | | |
| 0-7.6 | 3a[a] | 0.01a | 0a | 0.00a | 0a | 0.00a |
| 7.6-15.2 | 27a | 0.13a | 0b | 0.00b | 2b | 0.01b |
| 15.2-22.9 | 95a | 0.26a | 7b | 0.01b | 0b | 0.00b |
| 22.9-30.5 | 43a | 0.11a | 22b | 0.02b | 0b | 0.00b |
| 30.5-38.1 | 25a | 0.08a | 32a | 0.11a | 0a | 0.00a |
| | | | Sweetgum | | | |
| 0-7.6 | 2a | 0.01a | 0a | 0.00a | 2a | 0.01a |
| 7.6-15.2 | 112a | 0.81a | 10b | 0.01b | 23b | 0.05b |
| 15.2-22.9 | 257a | 0.89a | 35b | 0.04b | 38b | 0.12b |
| 22.9-30.5 | 123a | 0.42a | 13b | 0.01b | 75b | 0.17b |
| 30.5-38.1 | 40a | 0.06a | 23a | 0.03a | 40a | 0.04a |

[a]Row values for each root parameter followed by different letters are significantly different at P = 0.01.

Although both sites had similar available water holding capacities, the actual available water at Site 1 was higher than at Site 2. A water deficit occurred for only two months during the growing season at Site 1. In contrast, a water deficit existed from mid-June to mid-October at Site 2.

The relatively high soil moisture content at Site 1 minimized compaction effects on this site. Although variable, resistance was lower at Site 1 than Site 2 on all compaction treatments. In addition, bulk densities were lower and total and air-filled porosities were higher at Site 1. In contrast, seedlings at Site 2 were under water stress during most of the growing season, and bulk density and soil resistance were high. During the limited time that soil moisture potential at Site 2 was at field capacity, air-filled porosity was near or below 10 percent, the level considered by many to be limiting to plant growth. Consequently, seedlings at Site 1 had greater root growth responses than those at Site 2.

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# PINE GROWTH IMPROVEMENT ON LOGGING SITES

# WITH SITE PREPARATION AND FERTILIZATION[1]

W. H. McKee and G. E. Hatchell[2]

Abstract.--Tree-length logging with rubber-tired skidders suppressed volume growth of individual planted pines in the succeeding stand through age 12. Treatments tested for alleviating the site damage on the poorly drained Batheria soil were flat disking and bedding, in combination with 200-50-100 fertilizer, a 400-175-175 fertilizer and 15 tons of sawdust per acre, or no amendments. Survival at age 12 was not altered by logging but was reduced by fertilization due to self-thinning. Adverse effects of logging were mitigated by bedding or the lower fertilization treatment at age 12 in terms of tree heights and volume per acre. The higher fertilizer level did not cause a further increase in growth. Results to date suggest that fertilization of poorly drained sites is an inexpensive means of alleviating damage done by logging. If the area has been fertilized, bedding in addition to fertilization does not appear to add substantially to loblolly pine growth on this site.

## INTRODUCTION

Rubber-tired skidding of timber on Atlantic Coastal Plain sites can puddle and compact wet soils. As a result, growth of loblolly pine seedlings planted on skid trails and log decks or landings is usually poor compared to that on the unaffected areas (Foil and Ralston 1967, Hatchell 1970, Hatchell and et al. 1970, Hatchell 1981). Skidding on medium- to fine-textured soils usually reduces macropore space, and compaction is greatest when soil is moderately moist. When moisture is near saturation, skidders cause puddling (deformation of soil structure by plastic flow). Scraping of the forest floor and surface mineral soil has the potential of removing nutrients from skid trails and landings, further retarding tree growth. Since skid trails and log landings often cover a substantial proportion of a logged area, the loss in growth of the new stand to compaction and puddling or scraping of the surface can be considerable.

In the study reported here growth of planted loblolly pines on a clearcut area was observed for 12 years. Prior to planting, skid trails and a log deck were prepared in several ways and soil amendments were added to determine if cultural treatments could alleviate adverse effects of logging operations.

## METHODS AND MATERIALS

### Study Area

The study was conducted on a 30-acre clearcut on the Santee Experimental Forest, near Charleston, South Carolina. The soil series is Beathera, which is a member of the clayey, mixed thermic family of Typic Paleaquults. Beathera is classed as poorly drained and occurs on nearly flat land with low topographic position. The topsoil is loam or silt loam about 6 inches deep, and the subsoil is sandy clay. Soil samples collected from the surface 6 inches contained an average of 7 percent organic matter and had a pH of 4.2.

A well-stocked stand dominated by loblolly pine was clearcut for sawtimber during the summer of 1972, and logs were transported to a landing with an articulated rubber-tired skidder. The area was burned during the spring of 1972 to facilitate timber marking and to reduce competition from hardwoods and shrubs. A log landing and a network of primary skid trails converging at the log landing were laid out in advance of logging. Although rainfall was unseasonably low during logging, the soil retained a moderately high moisture content because of its low topographic position and high moisture-holding capacity.

Rubber-tired skidders formed ruts in primary skid trails averaging 5 inches deep and shoulders of ruts 4 inches high (each measured from soil surface). The depth of ruts is typical for logging under moderately moist conditions. Ruts

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formed on similar soils under wet logging conditions are commonly 1 to 2 feet deep. More than 10 trips with the skidders caused severe soil compaction. Measurements taken with a pocket penetrometer indicated that average soil strength or hardness on primary skid trails often exceeded 64 pounds per square inch and averaged three times greater on the primary skid trails than on uncompacted soil.

### Treatments and Experimental Design

A split-plot experiment was established on a clearcut after tree-length logging with rubber-tired skidders. Combinations of soil-compaction and site-preparation treatments were tested on major plots, which were replicated twice in randomized complete blocks. Amounts of fertilizer and an organic amendment were tested on subplots. Each block contained three major plots for testing randomly assigned site-preparation treatments. The plots were located on compacted soil in portions of primary skid trails and three were located nearby on uncompacted soil. Major plots measuring 30 by 198 feet were divided into three subplots, each 30 feet by 66 feet, or approximately 0.05 acre.

The three site-preparation treatments were: (1) spraying woody vegetation with herbicide during summer of 1972 but no mechanical site preparation (herbicide), (2) shearing trees at ground line, rootraking debris into windrows, and flat disking (disking), and (3) shearing trees at ground line, rootraking debris into windrows, and then preparing beds at 10-foot intervals (bedding). All mechanical treatments were completed in late fall 1972, when soil moisture was ideal for tilling. Two trips were made with the bedding machine on both uncompacted soil and compacted soil; the second trip was needed in the center of the skid trails to penetrate the hard, compacted soil. Bed elevation averaged approximately 1 foot above the original elevation, and the depth of tillage averaged 6 inches. Plots scheduled for flat disking were triple disked to a depth of 5 inches.

Each major plot was divided into three subplots and randomly assigned the following amounts of fertilizer and organic amendment: (1) unfertilized check; (2) medium level of fertilizer-200 pounds of nitrogen (N) as ureaformaldehyde, 50 pounds of elemental phosphorus (P) as triple superphosphate, and 100 pounds of elemental potassium (K) as muriate of potash per acre (medium level of fertilizer); and (3) 400 pounds of N, 175 pounds of P, and 175 pounds of K, in the above forms, plus a 3/4-inch depth of sawdust, which amounted to 15 tons of oven-dry sawdust per acre (high level of fertilizer). Ureaformaldehyde, a relatively expensive, slow-release form of nitrogen, was selected primarily to assure an adequate amount of slowly available nitrogen for breakdown of sawdust because nitrogen deficiency after sawdust application has been shown to persist for more than a year (Bollen and Lu 1957). Fertilizer and sawdust were broadcast and were mixed with soil during flat disking and bedding.

The treatments described above were also randomly assigned and installed on a single block on a log landing. Since treatments could not be installed on uncompacted soil nearby, data collected on the log landing were not statistically analyzed.

Loblolly pine seedlings were hand planted during March 1973. Three rows of seedlings were planted with 10-foot spacing between rows and 2-foot spacing along rows, initially providing 99 seedlings per subplot (2,178 trees per acre). On skid-trail plots, the central axis was oriented with the middle of the trail, and a row of seedlings was planted between a pair of ruts on soil compacted by skidding logs.

Diameters at breast height (dbh) and heights of all trees were measured at the end of the twelfth growing season. Total stemwood volume (outside bark) was computed using the equations of Clutter et. al. (1984). Border effects on adjacent subplots due to application of different amounts of fertilizer and sawdust were not obvious, so values for all trees on each sublet were included in the analyses.

Analyses of variance (ANOVA) were based on all trees in the subplots and on the 12 largest trees per subplot (crop trees). These crop trees can be expected to form the dominant stand in the next 5 to 10 years. Treatment means and interactions were anaylzed for statistical significant difference using Duncan's Multiple Range Test at $\underline{P}$ = 0.05.

## RESULTS

### Survival

Site preparation and fertilizer application affected survival of loblolly pine seedlings from the first through the fourth growing season (Hatchell 1981), but soil compaction during logging did not. Mortality was highest during the first growing season and least during the fourth growing season. Grasses and herbs were 3 to 6 feet tall during the first year, and competition from them appeared to cause most of the mortality. Mechanical site preparation increased pine survival, apparently by reducing competition during seedling establishment, but fertilizer application at planting time reduced survival, probably by increasing competition from grasses and herbs. Negligible mortality was attributed to insects. Fusiform rust infections were present on an average of 13 percent of the stems, but less than 1 percent of all seedlings were killed by this disease. Treatments did not significantly affect the incidence of fusiform rust on stems.

A similar treatment effect on survival relationship was observed at age 12. At that time, survival by site-preparation treatment was 75% for bedding, 64% for disking and 53% for herbicide. The differences were statistically significant. Also, survival with zero fertilizer (77%) was significantly higher than survival with medium (60%) or high (55%) fertilizer amendments.

## Growth

The logging-disturbance x site-preparation x fertilizer interaction was not significant for any growth parameter, and the site-preparation x fertilizer interaction was significant only for height of all trees on plots (Table 1). Therefore, growth response is tabulated for the main effects of the three factors and for the logging disturbance x site-prepartion interaction and the logging disturbance x fertilizer interaction (Tables 2 through 5).

## Height

Average height of all trees and crop trees were increased by 6 to 10 percent by bedding (Table 2). Disking offered no improvement over the herbicide alone. Soil compaction did not affect tree heights. No improvement in height was found with the heavy compared to the medium fertilizer application. Fertilizer increased heights of all trees in plots receiving herbicide and disking treatments by 27 to 47 percent. Fertilizer did not improve tree heights in combination with bedding.

Fertilizer at the medium level increased tree heights of all trees by 4.7 feet on uncompacted soil, but had no significant effect on crop trees growing on uncompacted soil. On the compacted skid trails, the medium fertilizer treatment increased heights by 9.1 feet for all trees and 6.6 feet for crop trees. Soil compaction reduced heights without fertilizer both for all trees and for crop trees, but it had no effect with the fertilizer treatments.

## Diameter

Average dbh for all trees in stand or for crop trees was unaffected by site-preparation treatments (Table 3). Fertililzer application increased dbh of all trees by 33 to 36 percent. Compaction reduced dbh of all trees. Overall means were 4.14 and 3.86 inches for the uncompacted vs. compacted sites. Diameters of crop trees on uncompacted plots were not improved with fertilizer, but on the compacted skid trail fertilizer increased diameter by 20 to 29 percent.

## Basal Area

Soil compaction did not affect the total basal area of all trees in the stand, but bedding increased basal area by 27 to 37 percent compared to overall for disking and herbicide treatments, respectively (Table 4). Site preparation did not affect basal area of crop trees, which indicates that survival did not interact with diameter growth. Fertilizer applications increased basal area of all trees about 56 percent when soil was compacted but had no effect on uncompacted soil. Fertilizer increased basal area of crop trees by 29 to 40 percent regardless of compaction treatments which showed no significant effect.

TABLE 1. Significance levels of main effects and interaction of site-preparation and fertilizer treatments and logging disturbance based on ANOVA's of height, diameter breast high, basal area, and stemwood volume of all trees and crop trees of 12-year old loblolly pine.

| Source of Variation[1/] | All trees in stand | | | | Crop trees | | | |
|---|---|---|---|---|---|---|---|---|
| | Height | DBH | Basal Area | Volume | Height | DBH | Basal Area | Volume |
| | | | | --- -P----- | | | | |
| DISTURB | 0.263 | 0.039 | 0.231 | 0.331 | 0.320 | 0.072 | 0.095 | 0.182 |
| SITEPREP | .024 | .196 | .001 | .001 | .033 | .637 | .470 | .882 |
| DISTURB x SITEPREP | .726 | .682 | .145 | .226 | .226 | .340 | .399 | .395 |
| FERT | .001 | .001 | .105 | .017 | .001 | .001 | .001 | .001 |
| DISTURB x FERT | .008 | .257 | .044 | .051 | .003 | .044 | .075 | .041 |
| SITEPREP x FERT | .011 | .119 | .716 | .732 | .151 | .172 | .130 | .268 |
| DISTURB x SITEPREP x FERT | .954 | .701 | .765 | .859 | .469 | .152 | .179 | .299 |

1/DISTURB = logging, disturbance; SITEPREP = site preparation; FERT = fertilizer

Table 2.--Height of all trees in stand and of crop trees at age 12, by site-preparation and fertilizer treatments and classes of logging disturbance.

| Treatments | Height of all trees in stand | | Height of crop trees | |
|---|---|---|---|---|
| | Uncompacted soil | Compacted soil | Uncompacted soil | Compacted soil |
| | Feet | | | |
| Site Preparation | | | | |
| Herbicide | 34.2b2/ | 33.6b | 42.6b | 43.2b |
| Disking | 33.5b | 31.7b | 40.8b | 42.2b |
| Bedding | 37.1a | 36.9a | 45.4a | 45.2a |
| Fertilizer | | | | |
| Zero | 31.8b | 27.2c | 42.8a | 38.0b |
| Medium | 36.5a | 36.3a | 44.7a | 44.6a |
| High | 36.7a | 38.2a | 44.1a | 46.7a |
| Means, logging disturbance1/ | 35.0 | 33.9 | 43.9 | 43.1 |

1/Means for logging-disturbance classes with an underscore are not significantly different at *P* = 0.05.

2/Means for the site-preparation x logging-disturbance interaction or for the fertilizer x logging-disturbance interaction followed by a common lowercase letter are not significantly different at *P* = 0.05.

Table 3.--Diameter breast height of all trees in stand and of crop trees at age 12, by site-preparation and fertilizer treatments and classes of logging disturbance.

| Treatments | Dbh of all trees in stand | | Dbh of crop trees | |
|---|---|---|---|---|
| | Uncompacted soil | Compacted soil | Uncompacted soil | Compacted soil |
| | Inches | | | |
| Site preparation | | | | |
| Herbicide | 4.24a2/ | 3.92a | 6.21a | 6.06a |
| Disked | 4.03a | 3.67a | 6.32a | 5.82a |
| Bedded | 4.16a | 4.00a | 6.05a | 5.95a |
| Fertilizer | | | | |
| Zero | 3.52b | 2.99b | 5.82a | 5.10b |
| Medium | 4.38a | 4.27a | 6.34a | 6.13a |
| High | 4.52a | 4.32a | 6.43a | 6.59a |
| Means, logging disturbance1/ | 4.14 | 3.86 | 6.19 | 5.94 |

1/Means for logging-disturbance classes with an underscore are not significantly different at *P* = 0.05.

2/Means for the site-preparation x logging-disturbance interaction or for the fertilizer x logging-disturbance interaction followed by a common lowercase letter are not significantly different at *P* = 0.05.

Table 4.--Basal area of all trees in stand and of crop trees at age 12, by site-preparation and fertilizer treatments and classes of logging disturbance.

| Treatments | Basal area of all trees in stand | | Basal area of crop trees | |
|---|---|---|---|---|
| | Uncompacted soil | Compacted soil | Uncompacted soil | Compacted soil |
| | --------(Feet)$^2$ per acre-------- | | | |
| Site preparation | | | | |
| Herbicide | 116.1b2/ | 120.6b | 56.6a | 54.6a |
| Disked | 135.3b | 119.6b | 58.6a | 50.6a |
| Bedded | 163.2a | 160.4a | 53.4a | 51.6a |
| Fertilizer | | | | |
| Zero | 141.9a | 96.9b | 49.6b | 38.7b |
| Medium | 138.9a | 151.5a | 58.6a | 54.9a |
| High | 134.0a | 152.2a | 60.4a | 63.1a |
| Means, logging disturbance1/ | 138.3 | 133.5 | 56.2 | 52.3 |

1/Means for logging-disturbance classes with an underscore are not significantly different at $P = 0.05$.

2/Means for the site-preparation x logging-disturbance interaction or for the fertilizer x logging-disturbance interaction followed by a common lowercase letter are not significantly different at $P = 0.05$.

Table 5. Stemwood volume of all trees in stand and of crop trees at age 12, by site-preparation and fertilizer treatments and classes of logging disturbance.

| Treatments | Volume of all trees in stand | | Volume of crop trees | |
|---|---|---|---|---|
| | Uncompacted soil | Compacted soil | Uncompacted soil | Compacted soil |
| | -----(Feet)$^3$ per acre----- | | | |
| Site preparation | | | | |
| Herbicide | 1,645b2/ | 1,724b | 873a | 865a |
| Disked | 1,934b | 1,696b | 917a | 772a |
| Bedded | 2,427a | 2,377a | 877a | 844a |
| Fertilizer | | | | |
| Zero | 1,924b | 1,215b | 767a | 543b |
| Medium | 2,063a | 2,221a | 941a | 879a |
| High | 2,019a | 2,362a | 960a | 1,060a |
| Means, logging disturbance1/ | 2,002 | 1,932 | 889 | 827 |

1/Means for logging-disturbance classes with an underscore are not significantly different at $P = 0.05$.

2/Means for the site-preparation x logging-disturbance interaction or for the fertilizer x logging-disturbance interaction followed by a common lowercase letter are not significantly different at $P = 0.05$.

## Volume

Total stemwood volume of all trees on plots was increased 32 to 43 percent with bedding compared to disking and herbicide application, respectively, irrespective of soil compaction (Table 5). Bedding had no significant effect on volume for crop trees. Fertilizer at the medium or high level increased stem wood volume by 572 to 620 cubic feet per acre for all trees in the stand and 255 to 355 cubic feet per acre for crop trees with or without compaction.

## Responses on the Logging Deck

Results of the single replication on the log landing are not presented in the tables but are similar to those on the skid trails. For crop trees, heights averaged 46.2, 40.7 and 45.2 feet and d.b.h. averaged 6.42, 5.09 and 5.71 inches, respectively, for herbicide, disking and bedding. Crop trees averaged 39.2, 47.1 and 45.9 feet tall and 4.88, 6.11 and 6.23 inches in diameter at d.b.h. for the zero, medium and high fertilizer treatments.

# DISCUSSION AND CONCLUSIONS

Since trees were planted 2 feet apart in rows, crowding and self-thinning have affected average heights, diameters, and survival. For this reason the crop trees represent growth of trees which can be expected to have commercial value in 5 to 10 years. Whether one looks at basal area or total volume per acre of all trees or crop trees, there was no response to disking alone or to fertilization at a quantity greater than the medium treatment.

Bedding significantly improved tree height, stand basal area, and stem volume of all trees, but only increased height growth of crop trees. The medium level of fertilizer effectively increased growth variables for all trees on the plot as well as those designated as crop trees.

Height growth, average dbh, and total volume of crop trees were increased on compacted soil by the medium fertilizer treatment, but fertilizer did not improve growth on the area not disturbed by logging. This observation further supports the hypothesis that skidding operations remove topsoil and thus lower fertility and adversely impact marginally fertile loblolly pine sites. Another conclusion that can be gained from these data is that with dense planting as done in this study on the disturbed areas the higher fertility keeps the stand from stagnating and accelerates growth of dominate trees. It can be concluded that either bedding, which concentrates nutrients in the planting row, or fertilizer application will mitigate growth losses on skid trails.

Findings appear to have changed little since results were reported at age 4. Then as now, most of the growth response was to bedding and the medium fertilizer treatment (Hatchell 1981). The results further support the conclusion that bedding or application of a moderate level of fertilizer is effective in restoring growth losses on areas disturbed by logging. Where facilities and capital are limited, broadcasting fertilizer over the disturbed areas is effective in restoring site productivity.

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## Management of Established Stands

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PRECOMMERCIAL THINNING OF PINE REGENERATION IN UNEVEN-AGED STANDS[1/]

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**Abstract.**--Precommercial thinning is a proven management technique for increasing growth of loblolly (Pinus taeda L.) and shortleaf (P. echinata Mill.) pine regeneration in overstocked, even-aged stands, but no information has been available for uneven-aged management. This study compared growth of submerchantable pines over a 5-year period on unthinned plots (averaging 2,000 stems per acre) with growth on plots precommercially thinned to 800, 500, and 200 stems per acre. Hardwoods were controlled in all treatments. Annual growth gains were achieved by precommercial thinning but only at the lowest density level. Five-year radial growth of overstory pines was not improved by precommercial thinning of the understory pine component.

## INTRODUCTION

In uneven-aged stands of loblolly (Pinus taeda L.) and shortleaf (P. echinata Mill.) pine, natural seeding can result in dense patches of even-aged pine reproduction that exceed 1,000 stems per acre. Such intraspecific competition may restrict optimum growth and development of individual stems and thereby delay harvests.

Past research in overstocked, even-aged stands of loblolly pine has shown that substantial volume gains can be achieved when density is reduced to 500 to 750 pine stems per acre by precommercial thinning (Mann and Lohrey 1974). However, there has been no research to determine if natural regeneration in overstocked uneven-aged stands would respond to various levels of precommercial thinning. This study was conducted to determine if precommercial thinning of high-density, natural pine regeneration is a viable alternative to no thinning in uneven-aged loblolly-shortleaf pine stands.

## METHODS

### Study Area

The study was located on the Crossett Experimental Forest in Ashley County, Arkansas. Soils on the study plots are principally Bude (Glossaquic Fragiudalfs) and Providence (Typic Fragiudalfs) silt loam (USDA 1979). Both soils are loessial deposits with an impervious layer at 18 to 40 inches that impedes internal drainage. Both have high potential productivity for loblolly pine with a site index of 85 to 90 feet, base age 50.

Study plots were located throughout the 1,680-acre experimental forest in dense patches of advanced pine reproduction (stems less than 3.6 inches d.b.h.). The stands in which the plots were located contained a mixture of loblolly and shortleaf pines and had been managed under the selection system since the 1930's (Reynolds and others 1984).

### Study Installation

In the summer of 1980, 36 circular 0.05-acre plots were established. Prethinning densities for seedling, 1-inch, 2-inch, and 3-inch size classes averaged 539, 975, 443, and 190 pines per acre, respectively, on 0.02-acre measurement subplots across all treatments. All plots contained some overstory pines larger than 3.5 inches d.b.h. Plots were stratified according to initial percent pine stocking (McLemore 1981), then nine replications of four thinning treatments for pine regeneration were assigned at random.

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## Treatments

The four treatments included: (1) unthinned control, (2) thin to 800 stems per acre, (3) thin to 500 stems per acre, and (4) thin to 200 stems per acre. Treatments were based on recommended postthinning densities for rapid diameter growth in even-aged loblolly pine stands (Mann and Lohrey 1974). Well-formed dominants and codominants were left to provide uniform spacing. Dominants and codominants were understory pines less than 3.6 inches d.b.h. whose crowns were in the uppermost layer of the regeneration canopy.

Hardwoods were stem injected with herbicide in the summer of 1980, prior to thinning. Pines were hand-thinned in October 1980 by a two-man crew using a chain saw and machette. Thinning time was generally dependent on initial density and size of pines being thinned and ranged from 4 to 7 minutes per 0.05-acre plot. Hardwood regrowth and vines were controlled annually in mid-summer for 3 years after thinning.

## Measurements

Residual pines on thinned plots and 800 pretagged dominants and codominants per acre on control plots were measured in October 1980. Total height and height to live crown were taken to the nearest 0.1 foot and d.b.h. to the nearest 0.1 inch. All surviving pines were remeasured annually through the fall of 1985. At the end of each growing season, all surviving pines on control plots were tallied by 1-inch d.b.h. classes to monitor change in density as a result of natural mortality. In order to compute a pretreatment competition index (Daniels 1976) as a relative measure of point density on each plot, diameters of all merchantable-sized pines (those 3.6 inches in d.b.h. and larger) that fell within a plot radius of a 10-factor prism were measured to the nearest 0.1 inch, and their distances from plot center were measured to the nearest 0.1 foot in October 1980.

Five years after thinning, increment borings were taken at breast height from overstory pines on or adjacent to study plots to determine the effect of thinning on their radial growth. Radial growth was measured to the nearest millimeter for two 5-year intervals: 1976 through 1980 (pretreatment growth), and 1981 through 1985 (posttreatment growth). Distance from each overstory pine to plot center was measured to the nearest 0.1 foot and used as an independent variable in covariance analysis.

## Analysis of Data

Data from 34 of the original 36 plots were used in analysis of covariance to evaluate thinning effects on survival and on annual growth in d.b.h., basal area, total height, and volume for the understory pine component. Pretreatment competition index was used as the concomitant variable in the covariance analyses of annual growth. One plot was deleted from analysis because of logging damage unrelated to the study, and a second plot was deleted because of a heterogeneous competition index compared to other plots. Cubic-foot growth was calculated using stem taper equations developed for natural loblolly and shortleaf pine stands (Farrar and Murphy 1985). Percent survival among treatments was compared using the arcsine transformation.

Covariance analysis was also used to evaluate thinning effects on radial growth of overstory pines from 1981 through 1985. Independent variables were radial growth in the previous 5 years (1976 through 1980) and distance from subject tree to plot center. Differences among treatments in all covariance analyses were partitioned by Fisher's Protected LSD Test (Huitema 1980). Analyses were carried out at the 0.05 level of significance.

# RESULTS AND DISCUSSION

## Pine Regeneration

There was an average of 1,988 submerchantable pines (3.5 inches d.b.h. and smaller) per acre on control plots in 1980, when the study began. Five years later this density had declined to 844 stems per acre, while 175 pines per acre had grown to merchantable size (table 1). Approximately 50 percent of the pine regeneration present in 1980 survived five growing seasons where no thinning was done.

Survival of the dominant and codominant measurement pines ranged from 81 percent on control plots to 97 percent on the 200 stems-per-acre thinning regime. This indicated a significant increase in survival as density of pine regeneration was reduced by precommercial thinning (table 1).

Only 15 to 17 percent of submerchantable pines on the control, 800, and 500 stems-per-acre treatments grew to merchantable size in 5 years. In contrast, 66 percent of submerchantable pines on the 200 stems-per-acre treatment grew to merchantability. Drastic thinning to 200 stems per acre had left only the largest understory pines--they averaged almost 1 inch more in d.b.h. and about 5 feet taller than residual pines on the other three treatments (table 2). Although control plots had more ingrowth to merchantable size when compared to the other treatments (table 1), such ingrowth will vary depending upon the degree of overstory competition, initial diameters, and density of the regeneration. Therefore, ingrowth trends are not necessarily indicative of long-term growth potential on control plots.

Table 1.--Pine regeneration density and survival 5 years after thinning, with pretreatment competition index

| Thinning treatment | 1985 pine density: <3.5" d.b.h. | 1985 pine density: >3.6" d.b.h.[1] | 1985 pine density: Grew to 4" class after thinning | Survival of measurement pines | Pretreatment competition index[3] |
|---|---|---|---|---|---|
| | Stems per acre | | | Percent | |
| Control | 844 | 238 | 175 | 81a[2] | 3.80 |
| 800 Stems/acre | 617 | 172 | 106 | 90ab | 4.38 |
| 500 Stems/acre | 394 | 150 | 81 | 95 bc | 5.97 |
| 200 Stems/acre | 67 | 211 | 128 | 97 c | 4.87 |

1/ Includes overstory pines of sawlog and pulpwood size.

2/ Survival means followed by the same letter are not significantly different at the 0.05 level.

3/ $CI_i = \sum_{j=1}^{N} (D_j/D_i)/Dist_{ij}$; where:

$D_j$ = d.b.h. of competitor (j); $D_i$ = 1 for plot center (i).
$Dist_{ij}$ = Distance between plot center (i) and competitor (j).
N = Number of competitors counted with 10 BA factor prism.

Table 2.--Mean size of pine regeneration in 1980 and 1985

| Thinning treatment | D.b.h. 1980 | D.b.h. 1985 | Total height 1980 | Total height 1985 | Live-crown ratio 1980 | Live-crown ratio 1985 |
|---|---|---|---|---|---|---|
| | Inches | | Feet | | Percent | |
| Control[1] | 2.22 | 2.79 | 22.18 | 27.91 | 48 | 39 |
| 800 Stems/acre | 1.93 | 2.50 | 20.24 | 24.89 | 46 | 39 |
| 500 Stems/acre | 2.12 | 2.64 | 21.34 | 25.11 | 47 | 40 |
| 200 Stems/acre | 2.93 | 3.96 | 26.97 | 33.61 | 51 | 46 |

1/ Measurements based on 800 dominant and codominant stems per acre.

Dominants and codominants on the 200 stems-per-acre treatment plots outperformed similar pines of the other three treatments in diameter, basal area, height, and volume growth per tree (table 3). The covariate, pretreatment competition index (table 1), had a statistically significant influence in the analyses of pine regeneration growth.

After adjustment for pretreatment competition index, statistical differences between treatments were generally significant only for 200 stems per acre compared to any of the other treatments. With 500 stems per acre there was a significant diameter growth advantage over controls. There was no gain in growth by precommercial thinning to 800 stems per acre when compared to control plots where the only treatment was hardwood removal.

Even though thinning submerchantable pines to 200 stems per acre in these uneven-aged stands resulted in significant growth gains over other treatments, an annual growth rate of only 0.2 inch in diameter and 1.4 feet in height is about half what might be expected from comparable pines exposed to full sunlight (Cain 1985), as found in young even-aged stands. Since pine saw logs are worth more than small trees, most of the productive capacity of each acre in uneven-aged management is devoted to growing saw log-sized pines rather than maximizing growth of pine

Table 3.--Annual growth of pine regeneration from 1980 through 1985

| Thinning treatment | Adjusted mean annual growth per tree[1] | | | |
|---|---|---|---|---|
| | D.b.h. | Basal area | Total height | Volume |
| | Inches | Square feet | Feet | Cubic feet |
| Control | 0.08a[2] | 0.24a | 0.90a | 0.04a |
| 800 Stems/acre | 0.10ab | 0.25a | 0.83a | 0.04a |
| 500 Stems/acre | 0.14 b | 0.46a | 1.11ab | 0.08a |
| 200 Stems/acre | 0.22 c | 0.85 b | 1.36 b | 0.16 b |

1/ Adjusted for overstory pine competition index.

2/ Columnar means followed by the same letter are not significantly different at the 0.05 level.

regeneration (Reynolds and others 1984).

Reynolds (1959) published the diameter distribution for a well-stocked loblolly-shortleaf pine stand to be managed on a 5-year cutting cycle for the production of sawtimber, with pulpwood, poles, and pilings as secondary products. Reynolds suggested that the number of submerchantable stems (3.5 inches in d.b.h. and less) should total less than 100 per acre. Based on results in the present study, density of pine regeneration should be reduced to, at most, 200 stems per acre to achieve growth gains. At least 100 submerchantable pines per acre should be retained to insure replacement of overstory pines as they are harvested.

Study plots in this study were established in well-stocked, mature pine stands that had been undisturbed for nearly 15 years prior to precommercial thinning. There were no major disturbances to the overstory pine component during the 5 years following thinning. However, with uneven-aged management, stand manipulation by scheduled cuts, hardwood competition control, and salvage of dead or dying trees occur at relatively short intervals of 5 to 10 years. These ongoing management practices tend to bring about random thinning of understory pine regeneration. As such, precommercial thinning may not be warranted in uneven-aged pine stands if these stands are being managed properly and have a wide range in size distribution for the submerchantable component.

Whether there is a need for precommercial thinning of pine regeneration in well-managed, uneven-aged stands of loblolly-shortleaf pine could not be answered by this study. However, there are rule-of-thumb recommendations regarding the need for precommercial thinning in even-aged stands. Chapman (1953) proposed that normal rates of diameter growth can be expected for loblolly pines in overstocked stands as long as the pines retain a 40-percent crown-height ratio. Likewise, Mann and Lohrey (1974) recommended that precommercial thinning in even-aged stands of less than 5,000 stems per acre be done only if live-crown ratios of dominants were expected to be less than 35 percent when the pines reached merchantable size. In the present study, the live-crown ratios for dominants and codominants averaged more than 45 percent in 1980 and more than 39 percent in 1985 (table 2). Since these crown ratios were within the range designated for normal growth, this may have been one factor contributing to the lack of significant growth response to thinning at all but the lowest density level. Owners of uneven-aged pine stands might use the live-crown ratio rule-of-thumb to determine the need for precommercial thinning of understory pines.

## Radial Growth of Overstory Pines

Based on the results of this study, it was quite evident that overstory pines exerted a negative influence on the growth of pine regeneration during the 5-year interval. The recommended maximum basal area for merchantable-sized pines in uneven-aged stands is 75 square feet per acre so that natural pine reproduction will become established and grow (Reynolds and others 1984). Yet it was not uncommon for overstory pine basal area to exceed 100 square feet per acre on study plots. Less obvious was whether or not dense patches of pine regeneration had a negative impact on the radial growth of overstory pines.

The number of overstory pines averaged from 2 to 3 per 0.05-acre plot with mean diameters of 18 to 21 inches d.b.h. (table 4). Distance of these pines from plot centers averaged about 21 feet or just within the 0.05-acre radius of 26.3 feet.

Table 4.--Radial growth of overstory pines

| Thinning treatment | Pines per plot | Distance to plot center | D.b.h. 1985 | Radial growth 1976-80 | Radial growth 1981-85[1] |
|---|---|---|---|---|---|
| | Number | Feet | Inches | Inches | Inches |
| Control | 3.0 | 23.8 | 19.5 | 0.52 | 0.53 |
| 800 Stems/acre | 2.7 | 21.2 | 19.4 | 0.57 | 0.50 |
| 500 Stems/acre | 2.9 | 20.6 | 21.2 | 0.51 | 0.58 |
| 200 Stems/acre | 2.2 | 21.3 | 18.3 | 0.53 | 0.53 |

1/ Means adjusted for radial growth in previous 5 years and for distance from subject tree to plot center.

Although analysis of covariance indicated that mean radial growth differences were just at the level of statistical significance, a difference of only 0.08 inch over a 5-year period was thought to be unimportant. Also, radial growth did not increase with decreasing understory pine density.

Therefore, in uneven-aged stands with mature loblolly and shortleaf pines averaging 20 inches in d.b.h. and up to 100 square feet of basal area per acre, radial growth of the overstory pines was not impaired by patches of up to 2,000 understory pines per acre in the absence of hardwood competition. Results might have been entirely different if measurements had been taken in stands where overstory pines had not reached maturity or where there were higher understory pine densities and dry years.

## SUMMARY AND CONCLUSIONS

Past research has shown that volume growth of loblolly pine regeneration in even-aged stands will be maximized when the density is 500 to 800 stems per acre. To improve growth in overstocked stands of pine regeneration, density can be reduced to recommended levels by precommercial thinning. Although optimum densities have been established for even-aged stands, there were no comparable density guidelines for uneven-aged stands of loblolly-shortleaf pines that have high-density regeneration.

This study compared growth of submerchantable pines over a 5-year period on unthinned plots with growth on plots precommercially thinned to 800, 500, and 200 stems per acre. Hardwood competition was controlled on all plots. Annual growth gains were achieved by precommercial thinning but only at the lowest density level. Ongoing management practices at relatively short intervals of 5 to 10 years in well-managed, uneven-aged stands may result in random thinning of dense pine regeneration and negate the need for precommercial thinning.

Hand thinning was used in this study to insure uniform spacing of well-formed dominants or codominants. Such treatments may be practical on small woodlots, but large acreage would require more cost effective thinning methods such as mechanical treatment with rotary mowers or rolling-drum choppers.

Five-year radial growth of the overstory pines was not improved as a result of precommercial thinning of the understory pine component. The overstory consisted mainly of mature pines that averaged 20 inches in d.b.h. Radial growth of such pines may be more strongly influenced by overstory pine basal area than by understory pine density.

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## SLASH PINE SHOWS MIXED RESPONSE TO POTASSIUM FERTILIZER[1/]

Eugene Shoulders and Allan E. Tiarks[2/]

Abstract.--Potassium fertilizer was applied with and without nitrogen and phosphorus to two slash pine (*Pinus elliottii* Engelm. var *elliottii*) plantations in Louisiana. One plantation, fertilized at the time of establishment showed no response to potassium through age 13. The other plantation, thinned to 80 square feet of basal area per acre and fertilized at age 25, grew faster in height, diameter, and volume during the ensuing 9 years when potassium was included in the fertilizer mix. While differences in the age of the plantation when fertilizers were applied cannot be entirely ruled out as a reason for the difference in response, exchangeable soil potassium appears to be the most likely factor. The results suggest that slash pine should respond significantly to potassium fertilization if the surface soil (0- to 6-inch) layer contains less than about 20 pounds per acre (10 ppm) of exchangeable potassium.

### INTRODUCTION

Potassium fertilization is not a widely accepted management practice for southern pine plantations on Gulf and Atlantic Coastal Plain soils. Levels of exchangeable potassium in many of these soils, however, suggest that inadequate amounts of available potassium may limit growth of pines, especially where nitrogen and/or phosphorus deficiencies have been eliminated. Field and greenhouse studies have shown that even though soil potassium levels are low by agronomic standards, pines may or may not respond to potassium fertilization (McKee 1978; Pritchett 1979a, 1979b; Pritchett and Smith 1972; Pritchett and Comerford 1983). Results are reported in this paper of two field fertilizer trials in Louisiana--one where potassium increased growth of slash pine (Pinus elliottii Engelm. var elliottii) and one where it did not--and discusses possible reasons for the difference in response difference response.

### FERTILIZER APPLIED AT TIME OF ESTABLISHMENT

#### Methods

In one study, a direct seeded slash pine stand was fertilized at time of sowing. Potassium levels of 0 and 62 lb/acre were tested on plots that were fertilized with 34 lbs/acre of nitrogen and 44 lb/acre of phosphorus (fig 1). An unfertilized control was also included. Phosphorus was supplied either as polyphosphate in a liquid formulation supplied by Allied Chemical Corp. or as granular triple superphosphate. Since chemical formulation had no effect on response of pines to phosphorus, only an average for the two sources are reported. The polyphosphate liquid also served as the carrier for nitrogen and potassium.

Treatments were replicated three times in a randomized block design. Blocking was by soil series: two blocks on Beauregard soil (Plinthaquic Paleudult, fine-silty, siliceous, thermic) and one on Ruston soil (Typic Paleudult, fine-loamy, siliceous, thermic). Macro nutrient status and other selected properties of the unfertilized soil are listed in table 1.

Slash pine was row seeded on beds in November 1969. Fertilization, bedding, and seeding were accomplished with equipment designed to incorporate the fertilizers into the beds. Prior to this operation all residual trees and logging debris from the previous crop had been removed from the site and the area had been disked.

Beds were spaced 10 feet apart. After 1 year, trees were thinned and shovel transplanted using shovels as needed to produce an in-row spacing of approximately 6 feet. Measurement plots contained 4 rows of 25 trees each and were 0.14 acre in size.

Tree heights were measured after 1, 2, 3, 5, 6, 9, and 13 years. Diameters were included in the last three inventories. Total inside bark volumes at 6, 9, and 13 years were computed from Schmitt and Bower's (1970) $D^2H$ equation for young slash pine. Growth differences between treatments were tested by analyses of variance using a probability level of 0.05.

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986

2/ Principal Silviculturist and Soil Scientist, respectively, Southern Forest Experiment Station, USDA-Forest Service, Pineville, LA.

Table 1.--Selected properties of unfertilized soils from the two studies

| Soil Property | Unit of Measure | Age at Fertilization 0 Years | 25 Years |
|---|---|---|---|
| pH | unit | 5.2 | 4.8 |
| O.M. | percent | 2.2 | 2.1 |
| P | ppm | 3.6 | 1.6 |
| Ca | ppm | 245 | 128 |
| Mg | ppm | 43 | 21 |
| K | ppm | 27 | 8 |

Results

Individual degree-of-freedom comparisons showed that all nitrogen plus phosphorus fertilizations significantly increased average tree height at all ages, but that the additions of potassium had no significant additional effect on height (fig. 1). Although there was a consistent pattern for trees on potassium fertilized plots to be shorter at all ages than those receiving only nitrogen and phosphorus, the trend was not significant.

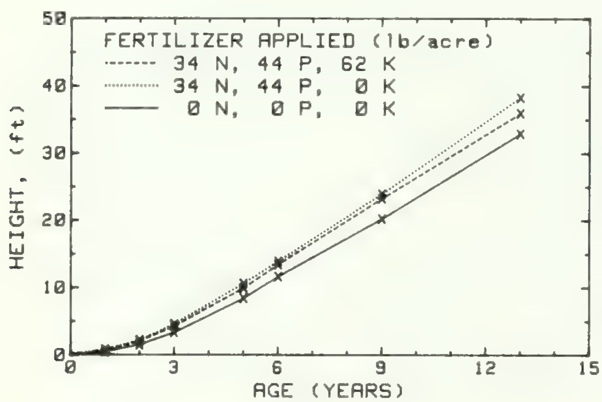


Figure 1. Effect of fertilization at time of sowing on height growth of direct-seeded slash pine.

Trees on nitrogen plus phosphorus treated plots were also significantly larger in quadratic mean diameter at 6, 9, and 13 than trees on control plots (fig. 2). As with heights, the addition of potassium had no significant effect on quadratic mean diameter.

The trends in total cubic volume per acre were similar to those for height and diameter, but only the difference at age 6 between fertilized and control treatments was significant (fig. 3). Greater mortality after age 6 on fertilized than on unfertilized plots may account for the apparent lack of response to fertilizer at the older ages. However, differential mortality cannot explain the lack of response to potassium; there were no significant differences in stocking at 9 and 13 years between fertilized plots that received potassium and those that did not.

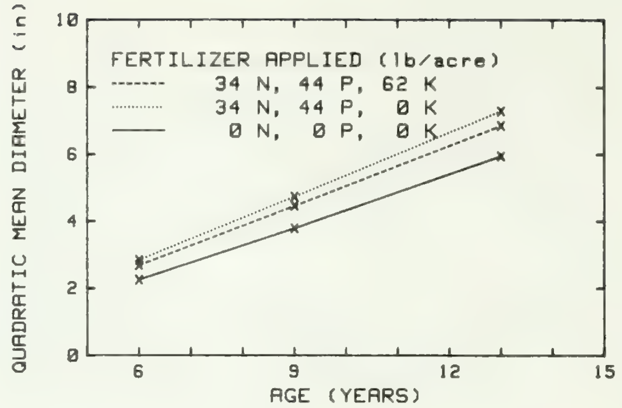


Figure 2. Effect of fertilization at time of sowing on diameter growth of direct-seeded slash pine.

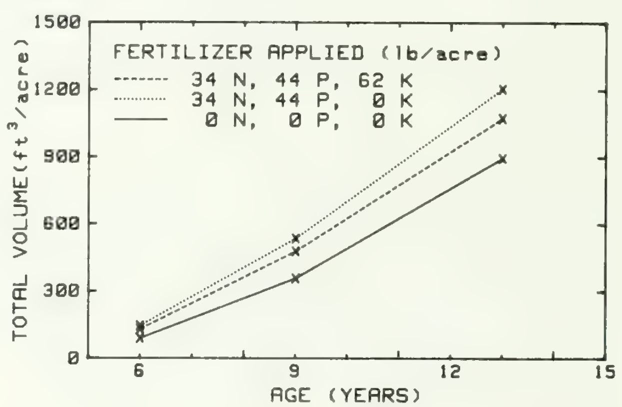


Figure 3. Effect of fertilization at time of sowing on total volume (i.b.) of direct-seeded pine at 6, 9, and 12 years.

FERTILIZATION FOLLOWING THINNING

Methods

The second study was established in a 25-year-old slash pine plantation. The stand had received a sanitation thinning at age 18 and was thinned again to 80 $ft^2$/acre of basal area immediately before fertilizers were applied. Actually, two experiments were established in this plantation: One in which plots having a gross area of 0.50 acre were fertilized by broadcasting the fertilizer over the surface of the entire plot, and one in which individual dominant and codominant trees were fertilized by distributing the material evenly over a circular area 33 feet in radius around individual stems. The soil was Caddo silt loam (Typic Glossaqualf, fine-silty, siliceous, thermic).

In the plot experiment, levels of 0 and 50 lb/acre of potassium were tested on plots

fertilized with 100 lb/acre of nitrogen and 22 lb/acre of phosphorus. A wider array of nitrogen plus phosphorus combinations was tested with and without 50 lb/acre of potassium in the experiment with individual dominant and codominant trees: no nitrogen and no phosphorus, no nitrogen and 22 lb/acre of phosphorus; 100 lb/acre of nitrogen with 22 lb/acre of phosphorus; 200 lb/acre of nitrogen with 22 lb/acre of phosphorus. Carrier for the nutrients were urea, triple superphosphate, and muriate of potash.

Treatments were replicated three times in the plot experiment and nine times in the individual tree experiment. The tests were established in March 1973 and reinventoried after 3, 6, and 9 years. Tree volumes were calculated by the height-accumulation procedure (Grosenbaugh 1954) and 3-, 6-, and 9-year periodic growth rates in diameter, height, and cubic volume were computed. Growth differences between treatments were tested by analyses of variance using the 0.05 level of probability.

## Results

In the plot experiment, potassium significantly stimulated average height growth of the stand during the second 3-year period, and this difference persisted after 9 years. Actual average height growth for 3, 6, and 9 years was as follows:

| Elapsed time in Years | Periodic height growth (feet) | |
|---|---|---|
| | No K | 50 lb/a K |
| 3 | 5.4 | 6.0 |
| 6 | 11.8 | 13.2 |
| 9 | 14.0 | 15.8 |

A similar trend in volume growth was not significant, and average diameter growth on plots was unaffected by potassium fertilization. The results might have shown significance had there been more replicates.

Potassium fertilization increased 9-year mean diameter growth of individual dominant and codominant trees by 0.27 inch (table 2), boosted 9-year average height growth by 2.3 feet and increased cubic volume growth per tree by 1.6 $ft^3$. Differences in diameter and height growth were significant and were accompanied by an 11-percent increase in cubic-volume growth. The latter difference had only an 11 percent probability of occurring due to chance. Our inability to precisely determine the total volume in 25- and 34-year old trees without destroying them undoubtedly contributed to the lack of significance.

## DISCUSSION AND CONCLUSIONS

Why did potassium fertilization stimulate growth of one plantation and not the other? Certainly, levels of exchangeable potassium in the unfertilized soil was a major contributing factor. Soil of the older and responsive plantation contained only 8 ppm of exchangeable potassium, whereas soil of the younger and unresponsive plantation contained 27 ppm--19 ppm more. Differences of this magnitude can be important. In a greenhouse study with Caddo soil (in pots) from two locations in central Louisiana, slash pine seedlings growing in unamended soil containing 35 ppm of exchangeable potassium produced 128 percent more dry weight in one year than those on soil containing 23 ppm (McKee 1978). Another important result in McKee's (1978) study was that the addition of 62 ppm of potassium to the less productive soil more than doubled seedling dry weight, whereas the same amount increased seedling dry weight on the more productive soil by less than 20 percent. Since pot studies place greater stress on soil nutrients than field experiments, these results are inappropriate for establishing critical levels of potassium in soil. Under field conditions, Pritchett and Comerford (1983) concluded that slash pine should respond to potassium fertilization if the soil contains less than 8 to 12 ppm of double-acid extractable potassium and other factors are not limiting. Our results support their conclusion.

Other factors that could have contributed to the lack of response to potassium in the younger plantations are deficiencies of other nutrients and competition from herbaceous plants. Differences in rates of fertilization had no apparent effect on growth response since the responsive plantation was fertilized with 50 lb/acre of potassium, while the unresponsive plantation received 62 lb/acre.

Table 2.--Effect of potassium fertilization at age 25 on 9-year height, diameter, and volume growth of individual dominant and codominant slash pine trees

| Growth Measured | Unit | K added (lb/acre) | | Difference | Probability |
|---|---|---|---|---|---|
| | | 0 | 50 | | |
| Diameter growth | Inches | 2.1 | 2.5 | 0.4 | 0.002 |
| Height growth | Feet | 12.6 | 4.8 | 2.3 | .008 |
| Volume growth | Cubic feet | 15.4 | 17.0 | 1.6 | .108 |

Application of nitrogen and phosphorus would have corrected any initial deficiencies of these nutrients in unfertilized soil that might affect response to potassium. Exchangeable calcium and magnesium levels appeared adequate for pines at both locations and were actually higher in soils of the unresponsive plantation than soils of the responsive one. Soil pH and organic matter were favorable for pine growth at both locations. In short, there were no obvious soil conditions that should limit the younger plantation's response to potassium.

When age or stage of development of the plantation at fertilization is considered, one would not expect germinating seeds and young seedlings to compete as vigorously with other vegetation for added nutrients as plantations that have overtopped this competition. The slower growth of the first study on direct seeded pines where potassium was added to the nitrogen and phosphorus suggests that potassium may indeed have stimulated growth of competing vegetation to the detriment of the pines. But the positive response of the plantation to nitrogen and phosphorus fertilizer indicates that the pines were able to compete. To say that the age or stage of development was a factor in the differential response is questionable since the response of herbaceous vegetation to fertilization was not measured.

Our results do imply that potassium fertilization should increase growth of slash pine plantations if other nutrient deficiencies have been eliminated and if the soil contains less that about 10 ppm, or 20 lb/acre, of exchangeable potassium in the 0- to 6-inch layer of surface soil.

ACKNOWLEDGEMENTS

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EFFECT OF LEGUMES ON PINE GROWTH IN THINNED

LOBLOLLY PINE PLANTATIONS [1/]

Terry R. Clason [2/]

Abstract.--Nitrogen fertilizer can stimulate residual pine growth in recently thinned pine plantations. Since leguminous plants may offer a cost effective alternative to nitrogen fertilizer, a study evaluating legume establishment methods and influence on residual pine growth was initiated in a 25-year-old loblolly pine plantation. Lespedeza cuneata and Trifolium subterraneum seed were broadcast in a loblolly pine plantation recently thinned to 100 TPA. Establishment methods included unburned and burned seedbeds that were either unfertilized or fertilized with 30 and 60 lbs/acre of phosphorus and potassium. First year lespedeza and clover stocking was better on the burned, fertilized seedbeds. After 5 years, lespedeza averaged 2,500 lbs of dry matter/acre on the burned, fertilized seedbed; clover was not present on any treatment. Pine growth and soil nutrient content was not influenced by lespedeza.

Keywords: sericea lespedeza, subterranean clover

## INTRODUCTION

Thinning and nitrogen fertilization can have a remedial effect on productivity of overstocked loblolly pine plantations. Ballard et al. (1980) reported 4 year net growth of thinned plantations exceeded unthinned plantations by 70 feet$^3$/acre after both were fertilized with 150 lbs of nitrogen/acre. Thinning reduces intra-specific competition by removing smaller pines and providing additional growing space for remaining pines. Nitrogen fertilizer stimulates residual pine crown growth which improves reoccupancy of additional growing space.

Nitrogen fertilizer growth enhancement in thinned stands could be obtained with leguminous plants. Jorgensen (1980) suggested that minimum acceptable annual nitrogen accretion rate for legumes in forests was 50 to 100 lbs/acre. If biologically derived nitrogen is available for pine use, then nitrogen availability over a 4-year period would be equivalent to the amount of fertilizer nitrogen applied by Ballard et al. (1980). In addition, a dense stand of leguminous plants could influence long-term site productivity by improving soil physical and nutritional characteristics.

A study was initiated at the Hill Farm Research Station, Homer, LA in a previously overstocked loblolly pine plantation to evaluate the combined effect of thinning and biologically derived nitrogen on residual pine growth. Sericea lespedeza (Lespedeza cuneata) and Mt. Barker subterranean clover (Trifolium subterraneum) were the legumes chosen for the study. Selection was based on criteria developed by Jorgensen (1980). The objectives of the study were to determine:

1. Efficient methods for lespedeza and sub-clover establishment;
2. Effect of lespedeza and sub-clover on soil nutrient levels; and
3. Short- and long-term effects of lespedeza and sub-clover on residual pine growth.

## METHODS AND PROCEDURES

The research area was a 4-acre, 25-year-old loblolly pine plantation growing on a Ruston fine sandy loam soil with an average site index of 63 at age 25. Plantation stocking level at age 20 was reduced from 850 to 400 trees per acre (TPA).

The experimental design was a randomized complete block with split plots. Main plot treatments were burned and unburned seedbed preparation. There were six split plot treatments, which included: 1) sub-clover with fertilizer (CLV/F); 2) lespedeza with fertilizer

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(LES/F); 3) sub-clover (CLV); 4) lespedeza (LES); 5) sub-clover and lespedeza (CLV-LES); and 6) control (CON). The plantation was divided into three 1.3 acre blocks with burned and unburned seedbeds replicated randomly in each block on a 0.6-acre plot. Split plot treatments were assigned randomly to 0.1-acre plots in each main plot.

In December 1981, the plantation was thinned to 100 TPA and seedbed preparation treatments applied to the appropriate plots. Immediately following seedbed preparation, phosphorus (P) and potassium (K) were applied at 30 and 60 lbs/acre, respectively, to the appropriate split plot treatments. Legumes were hand seeded at 10 lbs/acre with sub-clover being inoculated and applied in February, 1982 and lespedeza in March, 1982.

Soil samples were taken to a depth of 1 foot prior to, and 5 years after, legume establishment. Legume treatment stocking rates were estimated in May, 1982 and June, 1986 by averaging the number of plants found on 5-milacre plots within each 0.1-acre plot. Also, treatment dry matter production was determined for 1986. Individual tree data were collected in December, 1981 and June, 1986. Measurements included DBH, bark thickness, total height, height to base of live crown, and crown radius. All data were analyzed by ANOVA procedures, and individual mean differences were contrasted orthogonally.

## RESULTS AND DISCUSSION

Tree growth data were collected in June, 1986 because a hail storm in April damaged the plantation so severely that tree mortality occurred in June. Although growth data were analyzed and presented as the 5-year increment, the actual growth period was less than 5 years. In addition, hail damage prevented estimation of tree crown growth and development.

### Legume Establishment

Legume stocking was influenced by seedbed preparation and species (Table 1). Initial stocking levels (1982) were greater on burned plots. Sub-clover stocking averaged 20 plants/milacre on burned plots and 2 plants/milacre on unburned plots. No clover stocking differences were attributed to P and K fertilizer on either burned or unburned plots. Lespedeza stocking was greater than clover, averaging 76 and 45 plants/milacre on burned and unburned plots, respectively. The greatest initial stocking, 177 plants/milacre, was achieved with lespedeza on burned plots fertilized with P and K.

The more persistent legume understory was produced with lespedeza. Legume stocking levels in 1986 revealed that no sub-clover understory was present, and the lespedeza understory averaged 75 plants/milacre (Table 1). Lespedeza stocking on the fertilized treatments averaged 180 plants/milacre and was significantly greater than unfertilized treatments. Mean lespedeza stocking on burned fertilized plots was 242 plants/milacre, which exceeded stocking of the lespedeza fertilized unburned plots by 123 plants/milacre.

Significantly higher stocking rate on the burned LES/F treatment resulted in an understory that was two to six times larger than other treatments. This was shown by the 1986 dry matter production yields:

| Treatments | Yields: Burned | Yields: Unburned |
|---|---|---|
| | -------lbs/acre-------- | |
| CLV/F | 398 | 933 |
| LES/F | 2,537 | 1,262 |
| CLV | 927 | 855 |
| LES | 662 | 668 |
| CLV-LES | 736 | 897 |
| CON | 618 | 861 |

Improving lespedeza stocking at time of establishment with burning and fertilization enhanced development of a lespedeza understory. Jorgensen (1982) reported similar results for lespedeza following seedbed preparation and fertilization.

Table 1. Legume stocking levels, 1982 and 1986

| Treatment | 1982 Clover | 1982 Lespedeza | 1986 Clover | 1986 Lespedeza |
|---|---|---|---|---|
| | ---------plants/milacre---------- | | | |
| | Burned | | | |
| CLV/F | 19 | --- | --- | --- |
| LES/F | --- | 177 | --- | 242 |
| CLV | 25 | --- | --- | --- |
| LES | --- | 37 | --- | 16 |
| CLV-LES | 11 | 15 | --- | 5 |
| CON | --- | --- | --- | --- |
| | Unburned | | | |
| CLV/F | 3 | --- | --- | --- |
| LES/F | --- | 35 | --- | 119 |
| CLV | 1 | --- | --- | --- |
| LES | --- | 30 | --- | 24 |
| CLV-LES | 1 | 71 | --- | 48 |
| CON | --- | --- | --- | --- |

### Soil Nutrient Levels

Table 2 provides soil analysis data for organic matter, and P and K levels prior to legume treatment establishment. Initial soil nutrient levels did not vary among treatments. Mean values for all treatments were organic matter, 0.47 percent; P, 5 ppm; and K, 21 ppm. Organic matter levels, 5 years after establishment, did not vary among treatments and averaged 1.11 percent (Table 3). Soil concentrations of P and K were not influenced by burning or legume species. P averaged 6.0 and 7.3 ppm for the burned and unburned treatments, respectively,

while K averaged 31.6 and 22.6 ppm for burned and unburned. Soil concentrations of P and K for all fertilizer treatments averaged 9.2 and 35.8 ppm and were larger than the unfertilized treatments, which averaged 5.3 and 22.4 ppm for P and K, respectively.

There was no apparent relationship between net nutrient concentration changes during the 5-year growth period and understory density. The largest organic matter increase, 0.89 percent, occurred on the burned CLV/F treatment, which had no legume understory and the lowest dry matter production of 398 lbs/acre. Burned LES/F treatment had the most dense legume understory and the highest dry matter yield, 2,537 lbs/acre, but organic matter only increased 0.59 percent. Although inorganic nutrient changes were as erratic as organic matter changes, 1986 soil analysis indicated that the dense understory in the LES/F treatments did not deplete inorganic nutrient levels.

Table 2. Soil nutrient levels, 1981

| Treatment | Organic Matter | P | K |
|---|---|---|---|
| | percent | -----ppm----- | |
| | Burned | | |
| CLV/F | 0.39 | 5 | 27 |
| LES/F | 0.53 | 5 | 16 |
| CLV | 0.55 | 5 | 17 |
| LES | 0.53 | 5 | 18 |
| CLV-LES | 0.33 | 5 | 20 |
| CON | 0.48 | 5 | 21 |
| | Unburned | | |
| CLV/F | 0.61 | 5 | 17 |
| LES/F | 0.53 | 6 | 27 |
| CLV | 0.48 | 5 | 22 |
| LES | 0.35 | 6 | 19 |
| CLV-LES | 0.50 | 5 | 24 |
| CON | 0.42 | 5 | 22 |

Table 3. Soil nutrient levels, 1986

| Treatment | Organic Matter | P | K |
|---|---|---|---|
| | percent | ----ppm---- | |
| | Burned | | |
| CLV/F | 1.25 | 7 | 27 |
| LES/F | 1.12 | 6 | 54 |
| CLV | 1.09 | 6 | 32 |
| LES | 0.99 | 5 | 23 |
| CLV-LES | 0.97 | 5 | 36 |
| CON | 1.07 | 7 | 18 |
| | Unburned | | |
| CLV/F | 1.22 | 12 | 31 |
| LES/F | 1.28 | 12 | 31 |
| CLV | 0.99 | 6 | 24 |
| LES | 1.08 | 5 | 16 |
| CLV-LES | 1.21 | 5 | 19 |
| CON | 1.00 | 5 | 15 |

Individual Tree Growth

Significant tree growth differences were detected among treatments (Table 4). There were no growth differences between main plot treatments. Burned treatment DBH, height, and merchantable volume growth averaged 1.5 inches, 2.5 feet, and 4.4 $feet^3$, respectively, and unburned averaged 1.7 inches, 2.2 feet, and 5.0 $feet^3$. Control treatment tree growth was significantly less than all of the legume understory treatments. The largest tree DBH and volume growth occurred on the unburned CLV/F treatment, averaging 1.9 inches and 6.1 $feet^3$. The dense understory on the LES/F treatment did not increase or decrease tree growth. Average DBH, height, and volume for trees on the LES/F treatment was 1.6 inches, 2.4 feet, and 4.8 $feet^3$, while mean DBH, height, and volume for all treatments was 1.6 inches, 2.4 feet, and 4.7 $feet^3$.

Table 4. Mean tree growth between 1981 and 1986

| Treatment | DBH | Height | Merchantable Volume |
|---|---|---|---|
| | inches | feet | $feet^3$ |
| | | Burned | |
| CLV/F | 1.6 | 2.4 | 4.4 |
| LES/F | 1.7 | 1.6 | 4.9 |
| CLV | 1.6 | 3.2 | 5.1 |
| LES | 1.4 | 3.8 | 4.1 |
| CLV-LES | 1.5 | 2.8 | 3.9 |
| CON | 1.4 | 1.4 | 3.9 |
| | | Unburned | |
| CLV/F | 1.9 | 1.4 | 6.1 |
| LES/F | 1.5 | 3.0 | 4.7 |
| CLV | 1.8 | 2.5 | 4.9 |
| LES | 1.6 | 3.1 | 5.1 |
| CLV-LES | 1.6 | 1.4 | 4.6 |
| CON | 1.6 | 1.9 | 4.4 |

Tree growth data indicated that there was no growth response to a leguminous understory growing under widely spaced pines. Reducing pine stocking to 100 TPA may have masked any residual pine growth response that could have been attributed to leguminous plants. Site quality of the treatment plots varied greatly as indicated by treatment site indices:

| Treatments | Site Index Age 25 Burned | Unburned |
|---|---|---|
| | ---------feet--------- | |
| CLV/F | 62 | 66 |
| LES/F | 65 | 63 |
| CLV | 65 | 63 |
| LES | 62 | 65 |
| CLV/LES | 63 | 64 |
| CON | 64 | 61 |

Comparing site index with tree DBH and volume growth showed that the higher the site index, the greater the tree growth. This occurred regardless of the legume treatment. Since the experimental

design of the study did not block treatments on site quality, the probability of detecting significant growth responses among treatments was severely diminished.

## CONCLUSIONS

Sericea lespedeza has greater potential as a biological source of nitrogen for pine growth than sub-clover. Legume stocking results showed that lespedeza was easy to establish, persisted without additional maintenance, and produced a dense leguminous understory. Recommended lespedeza establishment procedures, which are similar to those reported by Jorgensen (1982), include seedbed preparation by burning and fertilizing, and seeding inoculated seed at 10 lbs/acre in late winter.

The heavy lespedeza understory that developed on the burned and fertilized seedbeds did not decrease soil nutrient levels or reduce tree growth. These short-term results would not justify the cost of establishing a lespedeza understory as a biological nitrogen source in thinned pine plantations growing on Ruston fine sandy loam soils.

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# EARLY RESULTS OF SILVICULTURAL AND ECOLOGICAL IMPACTS OF HARVESTING SYSTEMS IN THINNING LOBLOLLY PINE PLANTATIONS[1]

Timothy R. Bottenfield, Michael S. Golden, Ralph S. Meldahl, Jon P. Caulfield, Bobby L. Lanford, and Donna N. Terry[2]

Abstract.--A study was initiated in 1985 to document and compare silvicultural and ecological impacts of representative mechanized first-thinning systems in loblolly pine (*Pinus taeda* L.) plantations on the Upper Coastal Plain of the Southeast. Plots established in two stands were measured before and after thinning with a selective forwarder system. Stand ages were 15 and 17 years, and site indices were 85 feet at age 25 for both stands. Stems per acre at thinning were 669 and 468, and the residual stand densities after thinning were 262 and 173, respectively. High impact strata (areas defined by placement of vehicle corridors, whole tree bunches, log piles, and skid trails) encompassed 37 and 25 percent of the stands areas. Of the residuals, 54 and 32 trees per acre had observable damage from logging equipment. Scar area per damaged tree averaged 34.6 and 18.4 square inches in the two stands. A significant increase in soil bulk density occurred only in the corridors. Recently, plots were established in a 15-year-old stand (site index 85 at age 25) where selective forwarder and fifth-row skidder systems operated side by side. Measurements were obtained before and after thinning. Continued measurements on soils, growth, and mortality will be taken on these and other sites where selective forwarder and fifth-row skidder systems are operational.

## INTRODUCTION

Inventory data indicate that several million acres of pine plantations in the Southeast will have reached commercially thinnable size during the 1980's, with an annual potential of about 1,000,000 acres by the end of the decade (Knight and Sheffield 1980, Stokes and Lanford 1982). The majority of these plantations are loblolly pine (*Pinus taeda* L.) and about half are on forest industry lands (Knight and Sheffield 1980).

Thinning is a controversial topic among forest land managers in the South. The controversy begins with the question of whether to thin and continues with how and when to thin. However, it is generally accepted that the potential benefits from thinnings in well- to densely stocked southern pine stands include:

1. Greater control of the growing stock carried to the end of rotation (Walker 1982, Feduccia 1983).
2. Increased diameter growth.
3. Volume growth concentrated on fewer trees, yielding larger, more valuable trees at rotation age.
4. More cost effective late-rotation and final harvest in thinned stands than in unthinned stands.
5. Allows utilization of trees otherwise lost through natural mortality.
6. Keeps mortality losses of merchantable trees at a minimum by removing diseased, damaged, and suppressed trees.
7. Higher total merchantable volumes (including that removed in thinning) in moderately thinned plots carried to 30 to 35-year rotations than in unthinned check plots (Mann and Feduccia 1976, Blackwelder 1982, Clason 1982).
8. Reduced financial risk.

The application of thinning in pine plantations ranges between two extremes - completely selective and strictly row. Completely selective thinning removes trees based on silvicultural criteria such as quality, tree spacing, vigor, disease incidence, and/or crown position. Row thinning consists of removing rows of a plantation without regard to other considerations. This usually involves cutting either every second or third row.

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[1]Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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Many potential benefits are not achieved in row thinning. Since trees removed are chosen purely by their presence in a row, improvement in quality or size is entirely by chance. Damage from ice and wind is common in row-thinned stands and volume growth is typically less than in selectively thinned pine stands (Belanger and Brender 1968, Grano 1971, Feduccia 1983).

In the past, row thinning was sometimes considered to be more practical than selective thinning, and by some perhaps the only economic approach to thinning. Row thinning is readily accomplished with a wide variety of machinery (Anderson and Granskog 1974, Granskog 1982). However, with the development of small, highly maneuverable machinery, some mechanized systems for selective thinning can approach the efficiency and cost effectiveness of row thinning (Lanford and Stokes 1982, Stokes and Lanford 1982).

Systems are in use which are not entirely row or selective in application, but which employ a pattern of fifth or seventh-row removal combined with selective removal of stems from rows between the resulting access corridors. These systems employ standard-sized skidders in the wide corridors and either small feller-bunchers or chain saws for felling (Stokes and Lanford 1982, Lanford and Stokes 1985).

The objectives of this study are twofold. The first is to document and determine differences in major silvicultural and ecological effects of representative mechanized first-thinning systems. The second objective is to determine the economic ramifications of growth and site impacts of representative mechanized thinning systems.

## METHODS

Two types of study approaches are being taken in this project. One consists of a side-by-side installation of two mechanized thinning treatments with control plots left unthinned. The other approach consists of installing study plots on sites with thinning operations as they are actually performed in the field.

### Study Areas

Research plots have been established in three plantations to date. One thinning treatment was applied to two moderately to well drained plantations on the Upper Coastal Plain in Conecuh and Butler counties, Alabama (Boswell fine sandy loam and Luverne fine sandy loam-Smithdale sandy loam, respectively). A side-by-side installation of study plots to monitor two separate mechanized thinning treatments has been established on a moderately well drained plantation on the Upper Coastal Plain of Conecuh County, Alabama (Annemaine fine sandy loam). The loblolly pine plantations examined had site indices of approximately 85 feet (base age 25) and ranged in age from 15 to 17 years. Specific site selection criteria are as follows:

1. no previous thinning
2. minimum tract size of 40 acres
3. medium to high site index
4. maximum of 25 percent slope
5. stand age of approximately 15 years
6. pre-thinning density of approximately 600 trees per acre
7. removal of 250-350 trees per acre
8. maximum of 150 non-pine stems per acre greater than 4 inches in diameter at breast height

### Harvesting Systems

The two thinning systems chosen for study were selective forwarder and fifth-row skidder systems. Both systems are presently used in the Southeast. The forwarder system with its almost complete selectivity represents one end of the spectrum of feasible mechanized thinning systems. The fifth-row skidder system represents thinning systems which are neither purely row nor selective in application.

On the three sites where the selective forwarder system was used, small feller-bunchers cut 10 feet wide access corridors approximately one and one-half chains apart, then thinned selectively between corridors. In one pass, trees were cut from the corridors and on either side to half the distance between the next corridor. Whole tree bunches were placed perpendicular and adjacent to the corridors by feller-bunchers. A processing machine delimbed and bucked the trees from each bunch to seven and one-half-foot logs, stacking the logs next to the corridor, opposite the whole tree bunches. Slash from each tree was deposited in the corridor ahead of the processor. Subsequently, both the processing and forwarding machines were driven over the slash covered corridors, minimizing slash build up and soil damage. A forwarder then picked up and transported the logs to a graded road or deck, where it unloaded directly to a trailer or a pile for later loading.

Where the fifth-row skidder was used, skid trails were established by removing every fifth plantation row using a feller-buncher. Whole tree bunches were positioned in and aligned with the skid trail, and were skidded to a graded road or deck by a grapple skidder. In a second pass, the feller-buncher selectively thinned two rows to either side of each skid trail, again placing the bunches in the skid trail. These bunches were also skidded to a graded road or deck where the whole trees were processed into shortwood and loaded on trailers for transport to the mill (normally, the trees are gate delimbed and loaded tree length). Processing machines piled slash along the sides of the roads and decks. Skidders were driven over the slash when convenient, to compact the slash piles as much as possible.

## Measurements

Fifty tenth-acre fixed radius plots were established in the three plantations. Ten of these were check plots which were left unthinned. On each plot the following tree measurements and observations were made:

1. azimuth and distance to plot center (for relocation purposes and construction of plot maps)
2. diameter at breast height
3. increment core samples for radial growth information
4. crown class and ratio
5. total height and stem quality
6. disease incidence
7. amount and location of damage caused by logging equipment
8. proximity of logging damage to nearest high impact stratum (corridor, bunch, pile, and skid trail)
9. evidence of insect attack

Soil and site measurements included:

1. area comprised of each impact stratum
2. area covered by slash and bare soil
3. percent slope
4. species, size, and number of non-pine woody stems
5. soil core samples for bulk density and moisture content determination
6. soil horizon characterization

In addition to these measurements, extensive documentation was performed by video recording and photographing the operation of each machine. This has aided in the determination of types of damage attributable to each machine.

Measurements were taken prior to harvest and immediately thereafter. Yearly measurements are to be continued for at least three years.

## Analytical Procedures

Once the data base has been expanded to encompass information collected from more plantations, appropriate statistical procedures will be applied to determine the following:

1. percent of tract in each impact category
2. amount and degree of damage to residual stand as it relates to thinning
3. relationships between growth and damage
4. relationships between mortality and damage
5. relationships among tree mortality, tree and stand characteristics, and thinning pattern
6. relationships among growth, tree and stand characteristics, and thinning pattern
7. means and degree of variability of soil bulk densities for each impact category

# RESULTS AND DISCUSSION

## Stand Characteristic Changes

The three plantations examined were planted at 908, 726, and 871 trees per acre. Prior to thinning there were 669, 468, 542 (side-by-side forwarder treatment site), and 525 (side-by-side skidder treatment site) trees per acre. Post-thinning inventories showed residual stand levels to be 262, 173, 258, and 248 trees per acre, respectively (Figure 1). The amount of pre-thinning stand basal area ranged from 128 to 177 square feet per acre and residual stand basal areas varied from 64 to 88 square feet per acre (Figure 2). Pre-thin to post-thin increases in average tree diameter at breast height ranged from 0.58 inch to 1.25 inches. The largest increase was observed in a stand where the forwarder system was applied, and the smallest increase was seen in the stand where the fifth-row skidder system operated (Figure 3). This possibly reflects a difference resulting from the lower degree of selectivity in the skidder system.

## Harvesting Impacts and Damage

### Impact Areas

Corridors, skid trails, and areas where whole tree bunches and log piles were placed were classified as high impact strata. In the stands that the selective forwarder system thinned, 37, 25, and 30 percent of those stands' areas were in high impact strata. Eighteen percent of the stand thinned by the fifth-row skidder system was comprised of skid trails (percentage does not reflect the area in decks) (Figure 4). Ocular estimates of light slash (that being less than 1 foot in depth) and heavy slash (that being greater than 1 foot in depth) were obtained from each corridor and skid trail. On average, the amount of corridor area covered in slash in the forwarder system stands was 28 percent for light slash and 51 percent for heavy slash. Estimates of slash in the skid trails of the stand thinned by the fifth-row skidder method were smaller (slash in the skid trails was comprised of limbs and tops broken off during skidding, and hardwood and understory plant debris). An average of 65 percent of the skid trail area was covered by light slash, and only 5 percent by heavy slash. This was expected because the skidded trees were processed outside of the thinned stand, and most of the slash was piled on the sides of the surrounding roads and decks.

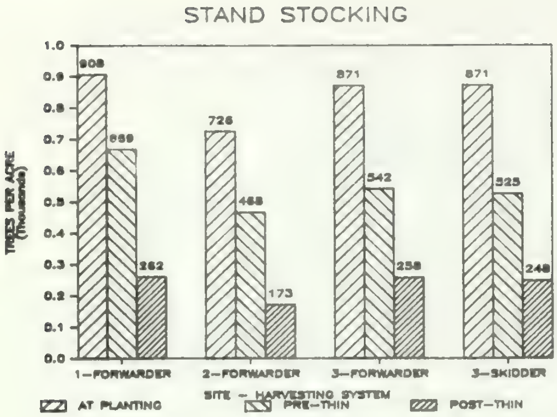


Figure 1.--Average loblolly pine stocking by site and thinning system. Sites 1 and 3 were 15 years old, and site 2 was 17 years old.

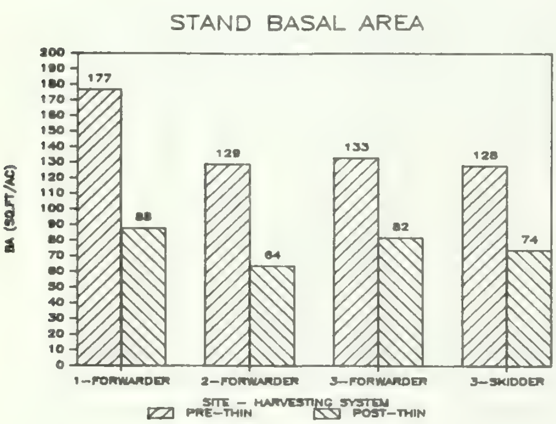


Figure 2.--Average loblolly pine basal area by site and thinning system. Sites 1 and 3 were 15 years old, and site 2 was 17 years old.

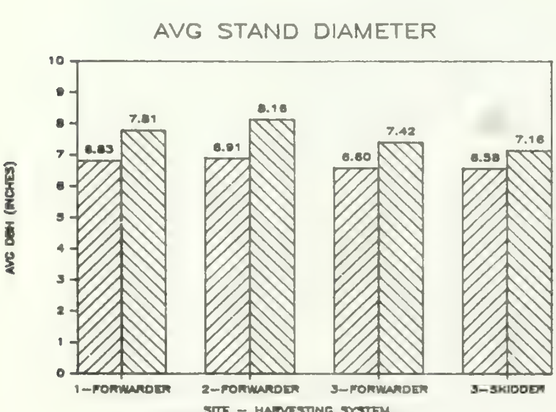


Figure 3.--Average pine stand dbh by site and thinning system. Sites 1 and 3 were 15 years old, and site 2 was 17 years old.

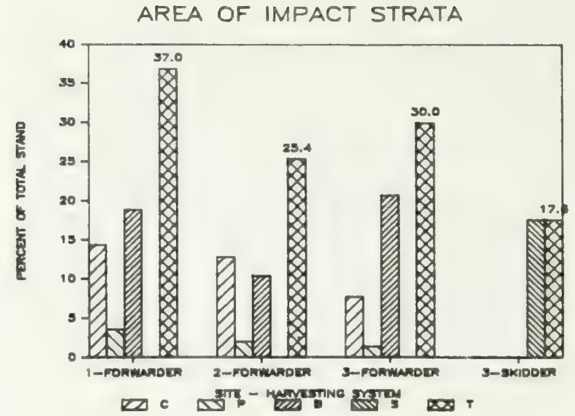


Figure 4.--Percent of stand area comprised of high impact strata (C = corridors, P = piles, B = bunches, S = skid trails, T = total) by site and thinning system.

Soil Bulk Densities

Three bulk density samples were extracted from the surface of each observable stratum on each plot. Pre- and post-thinning bulk density values for all test sites collectively were compared by stratum. Significant increases in compaction (Scheffe's multiple comparison procedure) were noted only in the visible tire tracks in corridors and skid trails (Figure 5). The visible tire tracks of the corridors and skid trails represented a small amount of the total area of the stands sampled (less than three percent).

Subsequent analyses compared pre- and post-thinning bulk density values by stratum for each test site individually. These showed that only two of the four test sites had a significant increase in compaction. The significant increases were found tc be in the visible tire tracks of one forwarder treatment site and the visible tire tracks of the skidder system treatment site (Figure 6).

A comparison of bulk density values for the side-by-side test site (where forwarder and skidder systems operated in the same stand) showed no significant differences in compaction among 10 strata (Figure 7). However, bulk density values obtained in the tire tracks of the corridors and skid trails were the highest. Strata represented included:

- 1f. Pre-thinned plots (forwarder system)
- 1s. Pre-thinned plots (skidder system)
- 2f. Thinned area of plots (forwarder system)
- 2s. Thinned area of plots (skidder system)
- 3f. Corridors - in tire tracks
- 3s. Skid trails - in tire tracks
- 4f. Corridors - between tire tracks
- 4s. Skid trails - between tire tracks
- 5. Whole tree bunch areas
- 6. Log pile areas

Although in some cases bulk densities significantly increased, compaction rates were low. It has been generally accepted that 1.4 g/cm$^3$ is the value that must be reached before growth losses occur in loblolly pine (Lull 1959, Mitchell and others 1982). None of the bulk density values of the existing four sites approach this level of compaction. The lack of serious compaction can be explained in part by the low soil moisture percentages (wet weight) which ranged from 12.3 to 17.0 for all test sites.

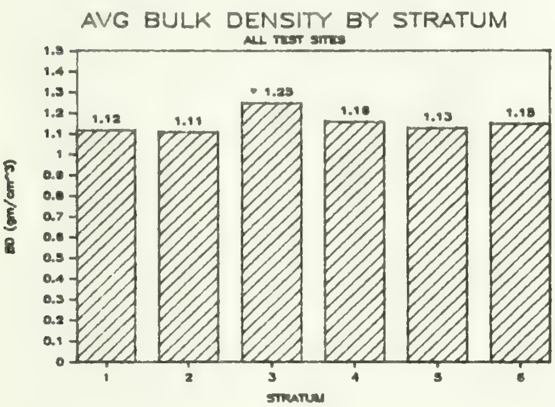


Figure 5.--Average bulk density values by stratum for all test sites collectively. Stratum 1 = pre-thinned sites, 2 = thinned area of sites, 3 = corridors and skid trails (in tire tracks), 4 = corridors and skid trails (between tire tracks), 5 = whole tree bunches, 6 = log piles. * Denotes a significant increase in compaction from the pre-thinned test sites (alpha level equal to 0.05).

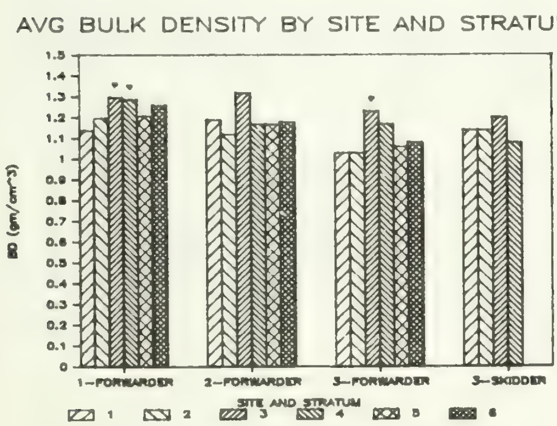


Figure 6.--Average bulk density values by site and stratum. Stratum 1 = pre-thinned plots, 2 = thinned area of plots, 3 = corridors or skid trails (tire tracks), 4 = corridors or skid trails (between tracks), 5 = whole tree bunches, 6 = log piles. * Denotes a significant increase in compaction from the pre-thinned test plots (alpha level equal to 0.05).

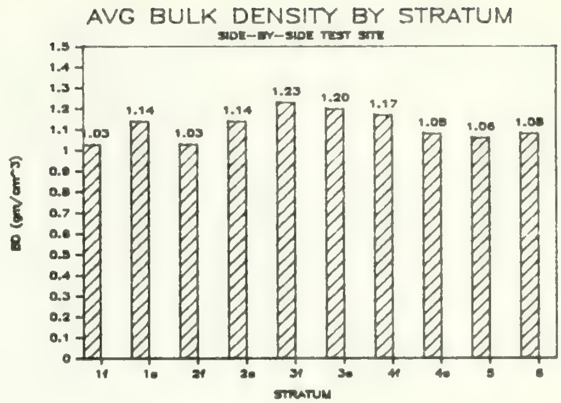


Figure 7.--Average bulk density for side-by-side test sites by stratum. Stratum 1 = pre-thinned plots, 2 = thinned area of plots, 3 = corridors or skid trails (tire tracks), 4 = corridors or skid trails (between tracks), 5 = whole tree bunches, 6 = log piles (f = forwarder system, s = skidder system). None are significantly different from pre-thinning values.

Tree Damage

The percentage of residual trees damaged averaged 20.6, 18.5, and 9.7 for the stands thinned by the forwarder system (Figure 8). In the stand thinned by the fifth-row skidder system, 13.7 percent of the residual trees were damaged. Average scar sizes for all stands ranged from 11.7 to 20.4 square inches (Figure 9). The average scar area per damaged tree in the forwarder system stands was 34.6, 18.4, and 14.6 square inches, whereas that in the skidder system stand was 31.6 square inches.

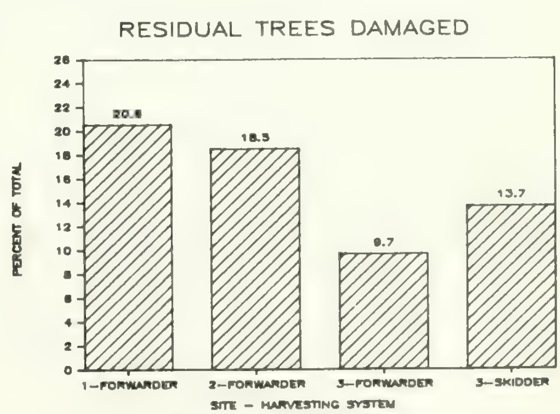


Figure 8.--Percent of residual trees visibly damaged by logging equipment (feller-bunchers, processers, forwarders, skidders) for each site and thinning system.

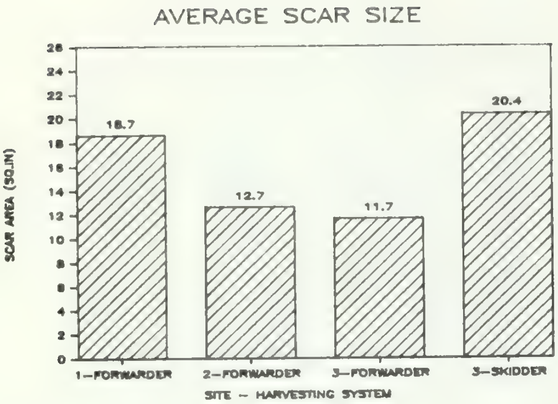


Figure 9.--Average scar size caused by logging equipment (feller-bunchers, processors, forwarders, skidders) by site and thinning system.

## SUMMARY AND CONCLUSIONS

Goals, methodology, and preliminary results have been presented. In the future, continued remeasurement of existing research plots and measurement of additional installations will provide a more complete data set. This larger data set will be analyzed using statistical procedures, enabling the researchers to identify trends within the two thinning systems. Much of the existing data represent information concerning the silvicultural impacts of the mechanized first-thinning systems. Additional data collection and further analyses will be used to compare the ecological and economic consequences of the different thinning systems.

## ACKNOWLEDGEMENT

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DEVELOPMENT OF INTERMEDIATE AND SUPPRESSED

LOBLOLLY PINES FOLLOWING RELEASE[1/]

B. F. McLemore[2/]

Abstract.--Eighty-two intermediate and suppressed loblolly pine (Pinus taeda L.) trees, ranging from 1.6 to 9.7 inches d.b.h. and 11 to 43 years of age were selected before a release cutting. The following 10 variables were measured for each tree: (1) height, (2) d.b.h., (3) age, (4) radial growth last 5 years, (5) crown volume, (6) percent live crown, (7) stem diameter at base of crown, (8) hardwood competition index before release, (9) pine competition index before release, and (10) pine competition index after release. All hardwoods on the area were injected following release cutting. Response of trees to release was evaluated by measuring d.b.h., basal area, stem diameter at base of crown, and height growth after five growing seasons. Average d.b.h. of the 78 surviving trees increased by 2.4 inches over the 5-year period. This represents an increase in basal area of 125 percent. A stepwise regression indicated that the two most important variables associated with diameter growth were diameter at base of crown and percent live crown ($R^2$=0.53). Trees 2 inches or less in diameter at base of crown, with 20 percent or less live crown, can be expected to show poor response to release.

## INTRODUCTION

The crown classification system most widely used in the United States categorizes trees as dominant, codominant, intermediate, or suppressed (Daniel et al. 1979). In thinning operations, intermediate and suppressed trees are often removed, leaving the better formed dominants and codominants. Often, however, it may be desirable to leave an intermediate or suppressed tree to occupy the site where mature trees have been harvested.

It is generally agreed that the live-crown ratio of a tree should be about 40 percent for optimum production of clear wood (Chapman 1953; Labyak and Schumacher 1954). If the ratio is allowed to decrease to 30 percent or less, the general reduction in vigor may cause substantial loss in diameter growth. No clear guidelines have been available, however, to enable timber markers to ascertain which intermediate and suppressed trees are capable of recovering and subsequently make good volume growth following release. Consequently, a study was installed to determine the ability of poorly formed, intermediate or suppressed loblolly pines with small crowns to recover and develop into acceptable crop trees when released.

## METHODS

The study was installed during the winter of 1979-80 in an uneven-aged loblolly-shortleaf-hardwood stand located in Ashley County, Arkansas. The site index for loblolly pine was about 90 feet at age 50. Pines ranged from seedlings to 18 inches d.b.h. in size, with a basal area of approximately 80 square feet per acre. Hardwoods were up to 15 inches d.b.h. and had a basal area of approximately 30 square feet per acre. The stand had been cut back to stocking levels of 10 to 50 percent for pine for another study. Stocking levels were based on guidelines used by the USDA Forest Service's Forest Survey. For this study, 82 loblolly pines were selected from the isolation strips of that study, before release. Ten measurements were taken for each tree at the time of selection:

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[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2/] Principal Silviculturist, Forestry Sciences Laboratory, Monticello, Arkansas, Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Department of Forest Resources and the Arkansas Agricultural Experiment Station.

1. Height
2. D.b.h.
3. Age
4. Radial growth last 5 years
5. Crown volume
6. Percent live crown
7. Stem diameter at base of crown
8. Hardwood competition index before release
9. Pine competition index before release
10. Pine competition index after release

No measurements were made of the hardwood competition index after release because all hardwoods were killed by injection with a herbicide when the study was installed. Competition indices were determined as described by Daniels and Burkhart (1975) and computed as follows:

$$CI_i = \sum_{j=1}^{n} (D_j/D_i)/DIST_{ij},$$

where $CI_i$ = Competition index of the $i^{th}$ tree,
$D$ = d.b.h. (in),
$DIST$ = Distance between subject tree i and $j^{th}$ competitor, and
$n$ = Number of competitors counted with 10 BAF prism.

The average age of the 78 surviving trees was 26 years when the study was installed, with ages ranging from 11 to 43 years and d.b.h. ranging from 1.6 to 9.7 inches and averaging 4.8 inches.

Response of trees to release was evaluated for each of four dependent variables: d.b.h., basal area, stem diameter at the base of the crown, and height growth after five growing seasons. Stepwise regression analyses were employed to determine the relationship of the 10 independent variables listed above to the four dependent variables measured after the 5-year period.

Camera points were established and pictures were taken of each tree when the study was installed and after five growing seasons.

## RESULTS

Diameter growth of the study trees was surprisingly good for the 5-year period following release. Average d.b.h. increased by 2.4 inches for the 78 surviving trees. Since the trees averaged 4.8 inches d.b.h. initially, this represents an increase in basal area of 125 percent for the 5-year period, or a 25 percent increase per year. This is even more dramatic when the suppressed condition of the trees is considered, along with the fact that average age of trees was 26 years when the study was installed.

Figures 1-4 provide visual examples of the suppressed condition of trees when the study was installed and the extent of recovery 5 years after release. The most evident feature in these photographs is that trees with extremely small, thin, misshapen crowns managed to recover quickly and start making phenomenal growth almost immediately. Because most trees, with the exception of the four that died, responded dramatically to release, none of the variables measured when the study was installed proved to be highly reliable predictors of a tree's ability to recover and make good growth. Moreover, there was no apparent relationship between the variables and mortality of the trees that died.

Nevertheless, a stepwise regression was run to determine the importance of the 10 variables measured in predicting 5-year d.b.h. growth. Table 1 lists the order in which the 10 variables appeared and the corresponding $R^2$ values. Radial growth for the 5-year period preceding installation of the study was the best single predictor, with an $R^2$ of 0.450. When two variables were used, percent live crown and stem diameter at the base of the crown were the best predictors, but the $R^2$ was only 0.531. Extending the number of variables to three or four involved height and pine competition index after release. Little was gained by using more than four variables.

When a stepwise regression for basal area growth was run, the $R^2$ values were somewhat higher. The three best predictors in this case were height, stem diameter at base of crown, and pine competition index after release, which gave a combined $R^2$ of 0.773. It is not surprising that a relatively high $R^2$ value for basal area growth was obtained with these variables because basal area growth is strongly dependent on d.b.h., and d.b.h. is strongly correlated with height ($r = 0.92$) and diameter at the base of crown ($r = 0.96$). Factors that were relatively unimportant in relation to d.b.h. growth and basal area growth included initial d.b.h., age, and competition indices before release. It is interesting to note that trees were able to recover and make good growth regardless of size, age, or previous competition, as evidenced by figures 1-4.

Regressions for stem diameter growth at the base of live crown resulted in very low $R^2$ values. The most important single independent variable was initial stem diameter at base of crown, which resulted in an $R^2$ of 0.292. The two best predictors, combined, were initial d.b.h. and percent live crown, with an $R^2$ of only 0.397. Again, competition indices before release were relatively unimportant.

A regression for 5-year height growth showed the best predictor to be percent live crown, with an $R^2$ of 0.200. Initial height, radial growth the last 5 years, age, crown volume, and stem diameter at base of the crown increased the $R^2$ slightly, but when the four best predictors were used, the $R^2$ was only 0.336.

Figure 1.--Left, 29-year-old tree, 3.1 inches d.b.h. at time of release; right, 5.8 inches d.b.h. 5 years later.

Figure 2.--Left, 30-year-old tree, 5.1 inches d.b.h. at time of release; right, 8.3 inches d.b.h. 5 years later.

Figure 3.--Left, 14-year-old tree, 5.3 inches d.b.h. at time of release; right, 8.0 inches d.b.h. 5 years later.

Figure 4.--Left, 17-year-old tree, 3.0 inches d.b.h. at time of release; right, 6.3 inches d.b.h. 5 years later.

Table 1.--Relative importance of variables measured on d.b.h. growth after 5 years.

| Number of variables | Adjusted $R^2$ | Identification of variables[1/] |
|---|---|---|
| 1 | 0.450 | 4 |
| 2 | 0.531 | 6,7 |
| 3 | 0.593 | 1,7,10 |
| 4 | 0.620 | 1,4,7,10 |
| 5 | 0.623 | 1,4,6,7,10 |
| 6 | 0.631 | 1,3,4,6,7,10 |
| 7 | 0.630 | 1,2,3,4,6,7,10 |
| 8 | 0.625 | 1,2,3,4,5,6,7,10 |
| 9 | 0.620 | 1,2,3,4,5,6,7,8,10 |
| 10 | 0.614 | 1,2,3,4,5,6,7,8,9,10 |

1/ 1. Height
2. Initial d.b.h.
3. Reciprocal of age
4. Radial growth last 5 years
5. Crown volume
6. Percent live crown
7. Stem diameter at base of crown
8. Hardwood competition index before release
9. Pine competition index before release
10. Pine competition index after release

Hence, d.b.h. growth, where the two best predictors gave an $R^2$ of 0.531, appears to be substantially more reliable for use in determining a tree's ability to recover than height growth.

Because diameter at the base of the crown and percent live crown were the two best predictors of d.b.h. growth (and these two variables are relatively easy to estimate quickly and accurately), it is suggested that they be used as a guide in determining the ability of a suppressed tree to recover when released. The prediction equation for estimating 5-year d.b.h. growth ($\hat{Y}$) following release is:

$$\hat{Y} = -0.14 + 0.36\ (DCB) + 0.033\ (CRPCT),$$

where DCB = diameter at base of crown in inches, and

CRPCT = percent live crown.

Figure 5 shows predicted 5-year d.b.h. growth where the independent variables are stem diameter at base of crown and percent live crown. This graph indicates that approximately 1 inch of d.b.h. growth would be expected over a period of 5 years for trees with a stem diameter at the base of crown of 2 inches and a live-crown ratio of 20 percent. Duerr et al. (1956) considered trees that grow 1.0, 1.5, and 2.0 inches in d.b.h. over a 5-year period to be in poor, medium, and high vigor classes, respectively. Hence, trees 2 inches or less in diameter at base of crown and with a live-crown ratio of 20 percent would be judged in the low vigor class and poor candidates for crop trees. Trees 2.5 inches in diameter at base of crown and with a live-crown ratio of 30 percent are in the medium vigor class (estimated d.b.h. growth of 1.5 inches in 5 years) and will probably make suitable crop trees. Trees described here as being in the low vigor class, with small diameters at base of crown and low live-crown ratios, are commonly referred to as "whips."

## CONCLUSIONS

Perhaps the most important information gained from this study is that suppressed loblolly pines 15 to 40 years old, with small, thin crowns, can recover quickly and make rapid growth following release. Though none of the variables measured proved highly reliable in predicting a tree's ability to recover, diameter at base of crown and percent live crown are two of the best and are the easiest to estimate quickly while marking trees.

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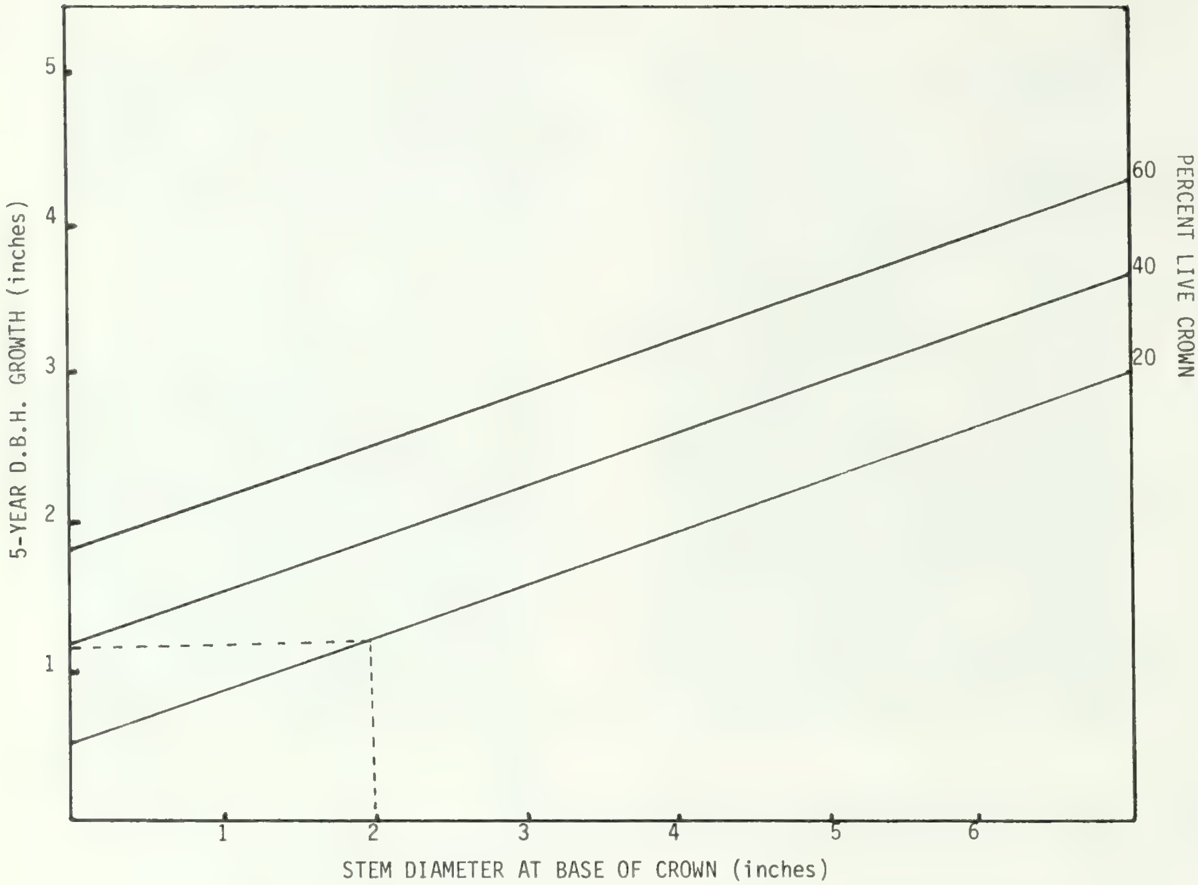


Figure 5.--Relationship of 5-year d.b.h. growth to diameter at base of crown and percent live crown. ($\hat{Y}$ = -0.14 + 0.36 (DVB) + 0.033 (CRPCT)).

# TEN-YEAR GROWTH OF RED AND WHITE OAK CROP TREES FOLLOWING THINNING AND FERTILIZATION IN THE BOSTON MOUNTAINS OF ARKANSAS[1/]

D. L. Graney[2/]

Abstract.--A thinning and fertilization study of 50-year-old northern red oak (Quercus rubra L.), black oak (Q. velutina Lam.), and white oak (Q. alba L.) was initiated in the Boston Mountains of Arkansas in the spring of 1975. Fertilizer applications of a nitrogen and phosphorus combination were broadcast at two levels to individual oaks that had received thinning or nonthinning treatments. Both levels of fertilization increased diameter growth of oaks in thinned and nonthinned stands. Maximum response to fertilization occurred during the first and second years after treatment. Response continued through the sixth year for white oak and through the eighth year for red oaks. A significant diameter growth response to thinning occurred during the third growing season after treatment for red and black oaks and the fifth growing season for white oak. From this point, the rate of annual diameter growth for all oaks in thinned stands increased annually through the tenth year.

## INTRODUCTION

Several hundred thousand acres of forest land in northern Arkansas support overstocked, even-aged, pole-sized stands of oaks and associated species. Although many stands are on medium-to-good sites (site index of 60 to 70 feet at 50 years), diameter growth averages only about 1 inch in 10 years. Since there are very few outlets for small diameter hardwoods, there has been very little intermediate cutting in these stands. However, because demands for hardwood sawtimber are increasing and inventories of mature sawtimber are small, some land managers have begun noncommercial thinning programs to accelerate growth of potential crop trees. Fertilization may further stimulate growth of crop trees. Research has shown that northern red (Quercus rubra L.), black (Q. velutina Lam.), and white (Q. alba L.) oaks will respond to nitrogen (N) and phosphorus (P) fertilization. Diameter growth of fertilized red oaks has been shown to increase by 45 to 70 percent and white oak about 60 percent. Red oaks responded more to higher levels of N, while white oak produced about the same response to medium and higher levels of N (Graney and Pope 1978a, 1978b; Graney 1983). In this paper, 10-year growth responses of red oaks (northern red and black oaks) and white oak in the Boston Mountains of Arkansas are summarized. Objectives were to determine how fertilizer applications affected diameter growth in thinned and nonthinned stands and to determine the effect of thinning on the diameter growth response to fertilization.

## METHODS

### Study Area

The Boston Mountains are the highest and southernmost member of the Ozark Plateaus physiographic province (fig. 1). They form a band 30 to 40 miles wide and 200 miles long from north central Arkansas westward into eastern Oklahoma. Elevations range from about 900 feet in the valley bottoms to 2,500 feet at the highest point. The plateau is sharply dissected, and most ridges and spurs are flat to gently rolling and are generally less than one-half mile wide. Mountain slopes consist of an alternating series of steep simple slopes and gently sloping benches.

Rocks in the area are sedementary and are of Pennsylvanian and Mississippian age, consisting of alternating horizontal beds of sandstones and shales. Annual precipitation averages 48 inches, with March, April, and May being the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Three study areas were selected in overstocked stands on mountain benches that range from 2 to 3 chains wide. Soils are deep, well-drained, medium-textured members of the Nella and Leesburg series (Typic Paleudults). They are derived from sandstone and shale colluvium and rated medium to high in productivity.

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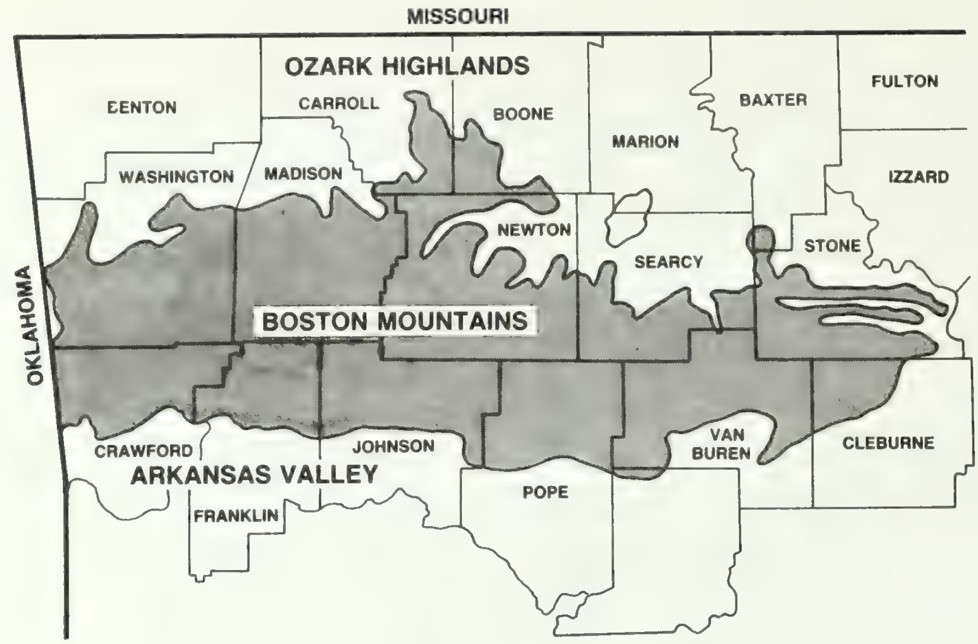


Figure 1.--The Boston Mountains of Arkansas.

## Sample Trees

In each stand, 48 red oak and 48 white oak crop trees were selected for the thinning and fertilizer treatments. Trees from each species group were arranged into 16 sets of 3 trees each. Members of each 3-tree set were uniform in diameter, crown size, and height and were located on essentially the same site conditions. Thin or nonthin treatments were randomly assigned to each three-tree set, and three fertilizer treatments were randomly assigned to trees within each set. In total, there were 144 red and black oaks and 144 white oaks at 3 locations.

## Tree Measurements

Diameter at breast height (d.b.h.) of each sample tree was measured to the nearest 0.01 inch. The diameter measurement point was identified by a painted band on each tree. Increment cores, extracted from the north, east, south, and west sides of each tree, were sealed in soda straws. These were used to determine tree age and to obtain a measure of past growth. Past annual radial growth was measured to the nearest 0.01 inch using a binocular microscope. Total height was also recorded for each tree.

## Thinning Treatment

Basal area around each sample tree was determined with a prism and was reduced to about 70 $ft^2$ by removing two major competitors and several smaller trees. Thinning was completed in March 1975. Average tree and stand characteristics following thinning in 1975, along with 10-year diameter and basal area values, are shown in table 1.

Table 1.--Mean stand and tree characteristics for red and white oak thinned and nonthinned treatments at the beginning and ending of the study

| Treatment | Age | Site Index | After Treatment D.b.h. | After Treatment Basal Area | 10-year Change D.b.h. | 10-year Change Basal Area |
|---|---|---|---|---|---|---|
| | years | feet | inches | $ft^2$/acre | inches | $ft^2$/acre |
| | | | Red Oak | | | |
| Thinned | 50 | 62 | 8.18 | 68 | 9.93 | 82 |
| Nonthinned | 50 | 62 | 8.48 | 120 | 9.73 | 115 |
| | | | White Oak | | | |
| Thinned | 52 | 59 | 8.26 | 66 | 9.98 | 82 |
| Nonthinned | 52 | 59 | 7.89 | 123 | 9.24 | 118 |

## Fertilizer Treatments

A combination of two fertilizers, ammonium nitrate (34-0-0) and diammonium phosphate (18-46-0) was used. Fertilizer treatments were: (1) No fertilizer (nonfertilized), (2) 200 lbs N + 45 lbs P per acre (200 lb treatment), and (3) 400 lbs N + 45 lbs P per acre (400 lb treatment). Fertilizers were surface broadcast in late April 1975 on a 0.01 acre circular plot surrounding each tree.

## Data Analysis

The study design was a split-plot with thinning representing the whole plots and fertilizer treatments the subplots. Data were analyzed by analysis of covariance with mean annual diameter growth for the 5-year period prior to treatment (1970-74) as the covariate. Differences among adjusted treatment means were tested using Duncan's multiple range test.

# RESULTS

## Response to Thinning

Red and white oak sample trees produced an immediate positive response to thinning, and the rate of annual diameter growth generally increased throughout the 10-year period of the study (table 2). Levels of response to thinning were greater and more apparent in the fifth through tenth years when fertilizer response declined and growth rates of nonthinned trees slowed to pretreatment levels or less.

Diameter growth rates of thinned red oaks were significantly greater than rates of nonthinned trees from the third through the tenth year and averaged more than a 75-percent increase over the last 5 years of the study. Over the 10-year period, thinning increased red oak diameter growth by about 40 percent.

White oak responded positively to thinning, but the level of response was lower than that observed for the red oaks (table 2). While differences in diameter growth between thinned and nonthinned white oaks were at or near significant levels through the fourth year following thinning, growth differences between nonfertilized trees receiving thin or nonthin treatments were not apparent until the fifth year. White oak produced the greatest response from years 6 through 10 where thinned trees averaged about 50 percent greater diameter growth than nonthinned trees.

## Response to Fertilization

Fertilization significantly increased diameter growth of red and white oaks over the 10-year period of the study, but the response varied between species and was influenced by the thinning treatment.

Table 2.--Mean annual diameter growth response of red and white oaks to thinning[a/]

| Year | RED OAK | | WHITE OAK | |
|---|---|---|---|---|
| | Nonthinned | Thinned | Nonthinned | Thinned |
| | ------inches------- | | ------inches------- | |
| 1975 | 0.155 | 0.179 | 0.162 | 0.181 |
| 1976 | 0.174 | 0.198 | 0.176 | 0.198*[b/] |
| 1977 | 0.135 | 0.173*[b/] | 0.152 | 0.169 |
| 1978 | 0.126 | 0.152* | 0.135 | 0.145 |
| 1979 | 0.127 | 0.169* | 0.142 | 0.161* |
| 1980 | 0.089 | 0.135* | 0.108 | 0.128* |
| 1981 | 0.114 | 0.183* | 0.135 | 0.179* |
| 1982 | 0.107 | 0.190* | 0.122 | 0.183* |
| 1983 | 0.107 | 0.196* | 0.114 | 0.189* |
| 1984 | 0.103 | 0.199* | 0.110 | 0.195* |
| Mean | 0.125 | 0.175* | 0.135 | 0.172* |

a/ Data averaged over all fertilizer rates and adjusted for differences in diameter growth using the 5-year period before thinning.
b/ * indicates statistically significant at $P<0.05$.

### Red Oak

Thinned red oaks produced the greatest overall response to fertilization and were the most responsive to the higher level of N (table 3). For the 10-year period, mean diameter growth of thinned, fertilized red oaks averaged 28 percent more than growth of thinned, nonfertilized red oaks for the 200 lb treatment and 42 percent more for the 400 lb level. Nonthinned red oaks produced about the same response to the 200 and 400 lb levels and averaged a 38-percent increase in diameter growth for each level of N.

Maximum response to fertilization occurred during the first 2 years after treatment. Response declined annually but was generally greater than nonfertilized trees through the ninth and tenth years. After the fifth growing season, thinned red oaks indicated no difference in response to the 200 or 400 lb treatments.

Over the 10-year period, growth response to fertilization for thinned red oaks averaged about 35 percent, slightly lower than the response reported for northern red oak in thinned stands in New York (Karning 1972) and higher than reported for thinned black oaks in the Missouri Ozarks (McQuilkin 1982). Ten-year increases in diameter growth of nonthinned Boston Mountain red oaks averaged 38 percent, which was slightly lower than observed for red oaks in the Tennessee Valley (Farmer and others 1970) and slightly higher than increases for northern red oak in West Virginia (Lamson 1978, 1980) and scarlet oak in Pennsylvania (Ward and Bowersox 1970).

Table 3.--Mean annual diameter growth response to fertilization for thinned and nonthinned red oaks[1/]

| Year | Nonthinned Fertilizer Treatment | | | Thinned Fertilizer Treatment | | |
|---|---|---|---|---|---|---|
| | Nonfertilized | 200 lb | 400 lb | Nonfertilized | 200 lb | 400 lb |
| | -------------inches------------- | | | -------------inches------------- | | |
| 1975 | 0.114a | 0.168b | 0.185b[2/] | 0.113a | 0.186b | 0.239c[2/] |
| 1976 | 0.120a | 0.190b | 0.211b | 0.128a | 0.202b | 0.263c |
| 1977 | 0.110a | 0.142b | 0.152b | 0.131a | 0.167b | 0.220c |
| 1978 | 0.105a | 0.136b | 0.136b | 0.126a | 0.148b | 0.182c |
| 1979 | 0.109a | 0.138b | 0.137b | 0.145a | 0.163a | 0.201b |
| 1980 | 0.095a | 0.090a | 0.081a | 0.125a | 0.138b | 0.141b |
| 1981 | 0.105a | 0.118b | 0.120b | 0.170a | 0.188b | 0.192b |
| 1982 | 0.100a | 0.115b | 0.105a | 0.178a | 0.195b | 0.197b |
| 1983 | 0.095a | 0.115b | 0.110b | 0.185a | 0.200b | 0.202b |
| 1984 | 0.092a | 0.112b | 0.105b | 0.192a | 0.202a | 0.204a |
| Mean | 0.100a | 0.138b | 0.138b | 0.142a | 0.181b | 0.202c |

1/Data adjusted for differences in diameter growth during the 5-year period before treatment.
2/Values in rows follwed by the same letter are not significantly different at the 0.05 level.

White Oak

In contrast to the red oaks, thinned white oak was much less sensitive to the two levels of N fertilization. Both levels produced about the same 10-year increase, 30 percent (table 4). Nonthinned white oaks produced the greatest response to the 400 lb treatment, averaging a 40-percent increase over the 10-year period.

White oak produced the maximum response to fertilization during the first 2 years after treatment. Fertilizer response declined annually, but remained significant through the fifth year.

Table 4.--Mean annual diameter growth response to fertilization for thinned and nonthinned white oaks[1/]

| Year | Nonthinned Fertilizer Treatment | | | Thinned Fertilizer Treatment | | |
|---|---|---|---|---|---|---|
| | Nonfertilized | 200 lb | 400 lb | Nonfertilized | 200 lb | 400 lb |
| | -------------inches------------- | | | -------------inches------------- | | |
| 1975 | 0.121a | 0.169b | 0.197c[2/] | 0.115a | 0.220b | 0.205b[2/] |
| 1976 | 0.127a | 0.184b | 0.218c | 0.131a | 0.234b | 0.227b |
| 1977 | 0.125a | 0.154b | 0.179c | 0.137a | 0.189b | 0.181b |
| 1978 | 0.116a | 0.135a | 0.155b | 0.127a | 0.150b | 0.160b |
| 1979 | 0.128a | 0.140a | 0.159b | 0.144a | 0.159a | 0.180b |
| 1980 | 0.105a | 0.112a | 0.108a | 0.135a | 0.125a | 0.125a |
| 1981 | 0.125a | 0.140a | 0.141a | 0.175a | 0.183a | 0.178a |
| 1982 | 0.115a | 0.127a | 0.123a | 0.180a | 0.187a | 0.183a |
| 1983 | 0.110a | 0.118a | 0.113a | 0.184a | 0.196a | 0.188a |
| 1984 | 0.105a | 0.112a | 0.112a | 0.190a | 0.199a | 0.195a |
| Mean | 0.109a | 0.144b | 0.153b | 0.144a | 0.188b | 0.184b |

1/Data adjusted for differences in diameter growth during the 5-year period before treatment.
2/Values in rows followed by the same letter are not significantly different at the 0.05 level.

Mean 10-year response of the thinned and nonthinned white oaks to the fertilizer treatments was about 33 percent, nearly the same as responses for fertilized white oak in Pennsylvania (Ward and Bowersox 1970) but only about one-half the response observed for white oak in the Tennessee Valley (Farmer and others 1970).

## DISCUSSION

Overall response of red and white oaks to fertilization was reduced by the general lack of response during the severe drought of 1980. Growth of all study trees was affected to some extent, but fertilized trees suffered the greatest reductions in growth (tables 3 and 4).

Thinned and nonthinned red oaks continued a significant growth response to fertilization through the ninth and tenth growing seasons after treatment, although actual growth rates for the nonthinned fertilized red oaks were relatively low. While annual diameter growth for thinned and nonthinned fertilized white oaks were slightly higher than nonfertilized trees over the 4-year period following 1980, levels of response were not statistically significant (table 4). In that fertilized red oaks maintained a fertilizer response following the 1980 drought, it is probable that the 5-year response will be the maximum white oak response for the 200- and 400-lb levels of N applied in this study.

Initial response of red and white oaks to thinning was relatively small, but differences between thinned and nonthinned trees increased rapidly after the third to fifth year. Annual diameter growth of thinned and nonfertilized red and white oaks continued to increase through 1984, while growth of nonthinned and nonfertilized trees declined to below pretreatment levels (fig. 2).

Differences in early levels of response to thinning by red and white oaks are probably due to differences in initial crown size and competitive position in these overstocked stands. On the same site, site index values for northern red and black oaks usually average 5 or more feet greater than white oak. The red oaks attain dominant crown positions and develop and maintain relatively large crowns. In mixed stands, most white oaks occupy lower crown positions and will suffer continuous reduction in crown size due to crowding but will persist for many years with very low rates of growth. As indicated by the consistent decline in diameter growth prior to thinning (fig. 2), all trees needed release, but the red oaks were generally in better condition to respond than were the white oaks.

Diameter growth for nonthinned and nonfertilized white oak trees over the period 1970-84 indicates the species' ability to survive and grow in these dense stands for long periods of time (fig. 2). Though generally in a less competitive crown position, subjected to intense crowding and competition, and possessing very small crowns, white oak maintained a fairly consistent rate of diameter growth over the 15-year period.

Nonthinned red oaks, on the other hand, were much more sensitive to competition and crowding and declined in diameter growth throughout the 1970-84 period (fig. 2). To maintain reasonably acceptable rates of diameter growth in these upland stands, red and white oak crop trees will require release from crown competition, and release should occur before crop trees suffer appreciable reduction in crown size.

The 10-year results of this study indicate that diameter growth of pole-sized red and white oaks can be significantly increased by thinning and/or fertilization. In overstocked stands where crop

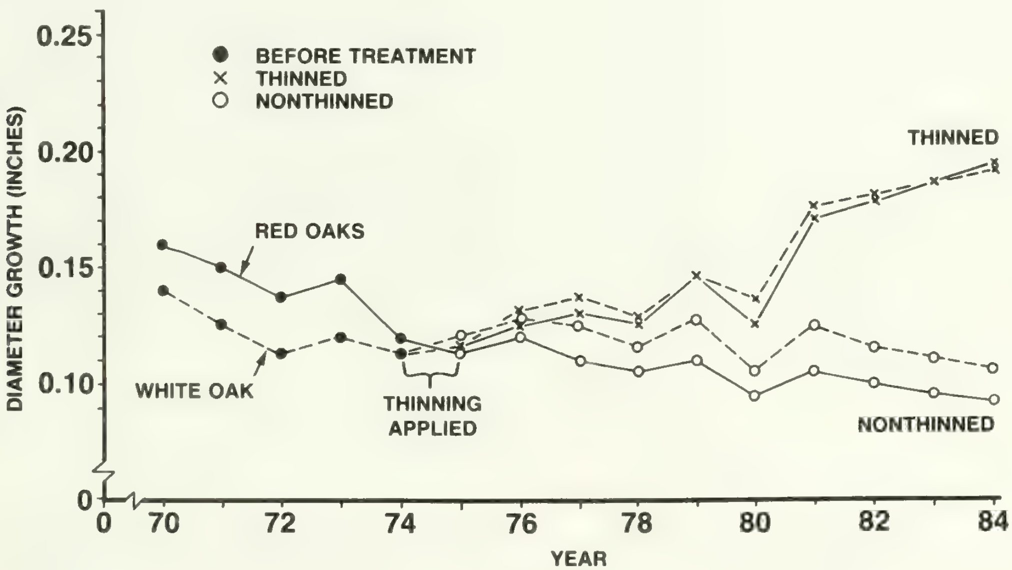


Figure 2.--Mean annual diameter growth of nonfertilized red and white oak crop trees before and after thinning.

trees have been subjected to extended periods of severe crowding, released trees will generally produce a positive response within 1 or 2 years after treatment, but a significant response to thinning may be delayed several years. Annual diameter measurements taken in conjunction with an oak growth and yield study in the Boston Mountain area indicate that free-to-grow red and white oak crop trees in 40- to 70-year-old stands on medium sites should average diameter growth of about 0.25 inch per year. To attain these growth rates, thinnings should be initiated before stands become overstocked and crop trees suffer appreciable reduction in crown size.

Fertilization with N and P can also increase diameter growth of oak crop trees and the increased growth rate will persist about 5 years for white oak and up to 10 years for red oaks. However, while differences in diameter growth between fertilized treatments were statistically significant, it is doubtful that the 10-year cummulative increase in diameter (0.3 to 0.5 inch) would justify the cost of a single commercial fertilizer application in these intermediate-aged stands. In considering silvicultural investments on these sites, regulation of stand density in younger stands should have first priority.

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# MANAGEMENT OPTIONS FOR SOUTHERN APPALACHIAN HARDWOODS: THE TWO-AGED STAND[1/]

Donald E. Beck[2/]

Abstract.--A harvest cut in a good site cove hardwood stand left 24 square feet per acre of dominant and codominant trees. The residual overstory was primarily northern red oak. Following harvest, the understory was chemically treated.

After 20 years, the residual overstory has responded well in terms of diameter and volume growth with little or no loss in bole quality due to sprouting. The regeneration that has developed is similar in species composition and size to that in an adjacent clearcut of the same age. Two-aged stands appear to have promise where even-aged stands are not desirable for esthetic or other reasons. For example, one might be able to maintain continuous mast production on a given site by use of the two-aged stand.

## INTRODUCTION

Southern Appalachian hardwood timber can be grown most effectively in even-aged stands. However, many owners would prefer an alternative that maintains at least some high forest cover continuously on the site. Some are motivated by a desire to improve the esthetic appearance of their forests. In other cases, the owner would like to maintain continuous mast production, e.g., keep oaks of seed-bearing age continuously on a site to avoid the 20- to 30-year period when even-aged stands will produce few, if any, acorns. All-aged stands maintained by single-tree selection methods have not proved workable (Della-Bianca and Beck 1985). Group selection may be a possible alternative. However, the recommended group sizes may approach the appearance of clearcutting, i.e., up to 2-acre groups. The frequent entry needed and the reputed difficulty of application also make this alternative less attractive.

Another alternative may be the two-aged stand created by irregular shelterwood (Smith 1986). This method is similar to the "two-storied high forest" of European foresters (Troup 1955). In the irregular shelterwood or two-storied high forest, a stand near midrotation age is cut heavily and an underwood, obtained naturally or introduced artificially, is allowed to develop. The two stories are then allowed to develop together.

This paper documents the development of one two-aged stand through the 20th year for the younger age class. Some suggestions and guidelines for management under this scheme are offered.

## THE SITE AND STAND

The 5.2 acre stand is on a northeast-facing slope of about 30 percent on the Bent Creek Experimental Forest. Soil is a deep friable loam of the Tusquitte series. Site index for oak (*Quercus* spp.) averaged 85 (Olson 1959). Species composition was predominantly chestnut oak (*Q. prinus* L.), northern red oak (*Q. rubra* L.), and yellow-poplar (*Liriodendron tulipifera* L.) in the overstory with an understory of red maple (*Acer rubrum* L.) and dogwood (*Cornus florida* L.). Basal area averaged 87 square feet per acre in 125 trees >5.0 inches d.b.h., mean stand diameter was 11.3 inches; however, diameter ranged up to 33 inches. The dominant stand age averaged 85 years.

## TREATMENT

A commercial timber harvest removed about two-thirds of the stand basal area. The residual stand contained 24 square feet of basal area per acre in 12 trees with mean diameter of 19.0 inches d.b.h. Species composition was almost exclusively northern red oak. Of 63 trees in the residual stand, there were 2 yellow-poplar and 2 black oak. The 59 northern red oak made up 94 percent of stand basal area.

After the harvest cut, all residual understory trees were injected or basal sprayed with 2,4,5-T in fuel oil. The following season the area was mist blown with 2,4,5-T to eliminate as much of the ground cover as possible, with the idea of establishing red oak seedlings from the residual oak stand.

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[1/] Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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## RESULTS

### Residual Stand Growth

Growth of the residual stand from 1965 to 1985 is summarized in table 1.

Table 1.--Twenty-year change in the residual overstory of a two-aged Southern Appalachian hardwood stand

| Year | Basal area | $\bar{D}$ | Board foot volume | Clear length |
|---|---|---|---|---|
| | ft$^2$/acre | Inches | fbm/acre | Feet |
| 1965 | 23.9 | 19.0 | 5,244 | 29.6 |
| 1985 | 41.3 | 25.0 | 9,670 | 31.4 |
| Diff. | 17.4 | 6.0 | 4,426 | +1.8 |
| Annual growth | 0.9 | 0.3 | 221 | |

The residual trees responded well to the unlimited growing space. Even the seemingly sparse stocking gave annual board-foot volume growth of 221 board feet per acre, which was about 60 percent of what might have been expected from a fully stocked stand (Schnur 1937).

### Diameter Growth Response

The residual trees immediately responded positively to the increased growing space despite their advanced age. Increment cores pulled 12 years after release were used to compare prerelease and postrelease growth ratios (fig. 1). A comparison with comparable trees in an adjacent untreated stand was also made.

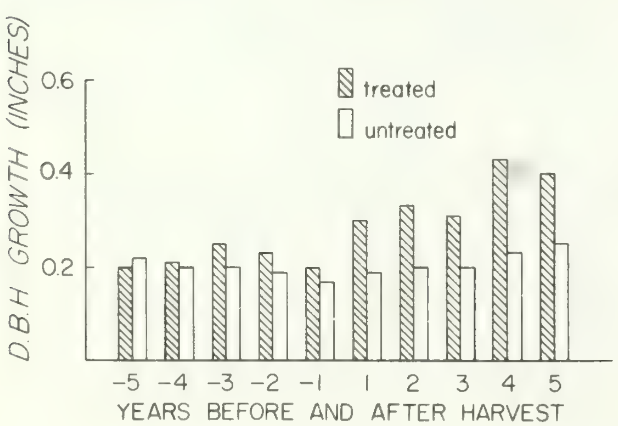


Figure 1.--Diameter growth of treated residual stand compared with untreated stand before and after treatment.

Posttreatment growth in the shelterwood was about double pretreatment growth after 4 years. Growth rate then declined to about 50 percent greater than both pretreatment and growth in the adjacent untreated stand. One could speculate that the developing second story began to compete more strongly for the resources of the site after 4 or 5 years.

### Bole Quality

Bole quality was apparently little affected by the rather drastic release of the residual trees. Average clear length at time of release was about 29.6 feet. Twenty years later, clear length averaged 31.4 feet--an inconsequential change. Some epicormic sprouts were initiated but were later shaded out by the developing understory trees.

### Regeneration

Distribution of regeneration by species and size class at stand age 20 is shown in table 2. It is quite evident that the regeneration stand is being dominated by yellow-poplar and red maple. Sweet birch (*Betula lenta* L.) is still a factor at age 20 but is rapidly falling behind. Other desirable species such as the oaks, hickory (*Carya* spp.), ash (*Fraxinus* spp.), etc., are still present but their numbers and particularly their size distribution indicate they will not be a significant part of the future stand. Miscellaneous understory species--mainly dogwood--are present in large numbers but are mostly small and not a serious threat in stand development at this point. Basal area in the regeneration portion of the stand for stems >1.0 inch d.b.h. averaged 70 square feet per acre.

Considering only the 100 largest stems per acre that are expected to form the bulk of the next stand, 60 percent are yellow-poplar. The effort to encourage the establishment and growth of northern red oak was not successful. The few new seedlings established were not able to compete with other species (Loftis 1983a).

### Comparison to Clearcut

Regeneration in the developing two-aged stand is quite similar to that in an adjacent clearcut of the same age. In terms of species composition both are dominated by yellow-poplar with red maple and sweet birch being prominent members (table 3). The major difference is in the amount of locust (*Robinia* spp.) present. This can probably be attributed to the herbicide treatment in the shelterwood. Although the herbicide was ineffective on species like red maple, it did kill most of the locust. Number of stems >1.0 inch d.b.h. is about the same in both stands. However, stems in the clearcut are larger, averaging 3.3 inches as opposed to 2.9 inches. Considering only the 100 largest stems per acre, the shelterwood averaged 7.3 inches and 54 feet tall. Comparable stems in the clearcut were 23 percent larger in diameter and 11 percent taller, at 8.9 inches and 60 feet tall.

Table 2.--Distribution of regeneration in a two-aged Southern Appalachian hardwood stand at age 20

| | Diameter class (inches) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
| Yellow-poplar | 147 | 156 | 56 | 36 | 31 | 17 | 11 | 6 | 8 | -- | 8 | 6 | 482 |
| Oaks | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3 |
| Birch | 36 | 47 | 47 | 11 | 11 | 14 | -- | -- | -- | -- | -- | -- | 166 |
| Locust | 8 | 22 | 31 | 3 | -- | 3 | -- | -- | -- | -- | -- | -- | 67 |
| Red maple | 106 | 89 | 56 | 19 | 19 | 11 | 3 | 3 | -- | 3 | -- | -- | 309 |
| Misc. I[a] | 22 | 12 | 3 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | 40 |
| Misc. II[b] | 323 | 89 | 11 | 8 | 3 | 6 | -- | 3 | -- | -- | -- | -- | 443 |
| | 645 | 415 | 204 | 80 | 64 | 51 | 14 | 12 | 8 | 3 | 8 | 6 | 1510 |

[a] Timber species.

[b] Nontimber species, e.g., dogwood.

Table 3.--Comparison of regeneration of Southern Appalachian hardwoods by irregular shelterwood method and clearcut at age 20

| | Stems per acre = >5.0 inches d.b.h. | |
|---|---|---|
| Species | Shelterwood | Clearcut |
| Yellow-poplar | 87 | 93 |
| Oaks | 0 | 11 |
| Sweet birch | 25 | 21 |
| Locust | 3 | 60 |
| Red maple | 20 | 33 |
| Misc. I[a] | 0 | 11 |
| Misc. II[b] | 3 | 4 |
| | 138 | 233 |

[a] Timber species.

[b] Nontimber species, e.g., dogwood.

## DISCUSSION AND CONCLUSION

To be successful, a system for creating and maintaining two-aged stands must meet at least two criteria. It must provide conditions under which regeneration can become established, grow, and mature. It must be possible for the residual older age class to grow for extended periods under very open stand conditions without excessive loss through windthrow, other mortality, and degrade.

In this instance the residual northern red oaks, although relatively advanced in age, responded well. Basal area increased by 73 percent and board-foot volume by 84 percent in the 20-year period. The annual board-foot growth rate of 221 board feet per acre was about 62 percent of what might be expected for a fully stocked stand on a comparable site. Bole quality was apparently unimpaired by the development of branches on the lower bole. Clear length changed little over the 20-year period. Other studies of development in sparse stands suggest that the rapid development of second story of trees serves to maintain clear length by shading out any epicormic sprouts that develop on the lower bole (Beck 1981). Of course, some species such as white oak (Q. alba L.) are more prone to sprout and may not be as desirable for this type of management.

Development of the reproduction into a second age class is progressing well in this case. Sufficient stems of desirable species are present to develop a fully stocked stand that can be carried to rotation. Species composition is quite similar to an adjacent stand created by clearcutting. Sapling development has been slowed somewhat by the older age class but not markedly so.

This study, along with our experience from several other studies, provides some guidelines for creating and maintaining two-aged stands. First, a low residual density is necessary to promote satisfactory development of the second age class so that it can form an integral part of the future overstory. Residual densities in the range of 20 to 30 square feet of basal area per acre seem appropriate. In this case, 25 square feet of basal area per acre was concentrated in a few large stems (mean d.b.h. = 19.0). In another study (Beck 1981), a residual stand of 26 square feet of basal area was left in 71 trees per acre (mean d.b.h. = 8.2 inches). The second age class that developed had become an integral part of the main canopy after 25 years--contributing about one-third of the stand with

two-thirds formed by residuals. Other studies demonstrate the need for a low residual basal area.

In a series of shelterwood cuts with residual basal area from 40 to 70 square feet per acre, basal area growth rates were 2 to 3 feet per year (Loftis 1983b). These stands closed quickly, within 10 to 15 years. In fact, Dale (1972) has shown that maximum board-foot growth rates may be obtained for upland oak stands with stocking as low as 40 square feet on average or better sites. Under such circumstances the stands close quickly and a second age class of relatively intolerant species is unable to develop.

As is the case with any type of regeneration method, treatment of the tolerant understory species is a necessity. Selective treatment with herbicides to prevent sprouting of undesirables would be the preferred method.

Although it is possible to create and maintain two-aged stands, the esthetic desirability remains to be evaluated. The regeneration process involves a fairly drastic treatment--one that creates a much stronger visual impact than single tree selection, which may have been envisioned. If the aim is to keep an oak component continuously on the site, then special measures to ensure the presence of large advance oak reproduction at the time of the regeneration cut, as suggested by Loftis (1983a), will be necessary. This would entail a treatment of the tolerant understory and light shelterwood cut perhaps 10 to 15 years prior to the main harvest cut.

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# DEVELOPMENT OF ADVANCED OAK REGENERATION AS INFLUENCED BY REMOVAL OF MIDSTORY AND UNDERSTORY VEGETATION[1/]

G. C. Janzen and J. D. Hodges[2/]

Abstract.--Pre-harvest release of advanced oak stems by either removal of unwanted vegetation or removal of unwanted vegetation plus cutting desirable stems to the ground was compared. After three years, there was no statistical difference between treatments in post-treatment height growth for oak stems. However, third-year results indicate that response to release is delayed. At that time, the mean height of oak stems which were cut to the ground surpassed the mean pre-treatment height and the growth rate was significantly greater than that of the controls or the uncut but released stems. Also, oak stems which were released but not cut to the ground showed an increasing rate of height growth in the third year. Height growth of oak regeneration in the control plots was very low in all three years.

## INTRODUCTION

Natural regeneration of hardwood stands is most often accomplished by commercial clearcutting and bringing the residual stems back to the ground (Kellison et al. 1981). Reproduction of hardwood species comes from one of three sources--stump sprouts, seedling sprouts, or true seedlings which are stems which germinate shortly before or after the stand is cut (Beck 1983). Young seedlings are an important source of regeneration only for the light-seeded, fast-growing species such as yellow-poplar (Liriodendron tulipifera L.) which are able to compete with sprouts or stems left after the clearcut. Young oak seedlings, which are the most commercially desirable species, grow too slow initially to compete with sprouts and other vegetation common in clearcuts. If desirable advanced reproduction of an adequate size and number is not present before the stand is harvested, it is doubtful that the next stand will contain species that are best suited for wood production (Sander 1972, Loftis 1982, Marquis 1982, Johnson and Shropshire 1983).

Several systems have been developed for evaluating the regeneration potential of hardwood stands (Sander et al. 1976, Johnson 1980, Marquis and Bjorkhom 1982). Regeneration potential is based on the size and number of desirable stems of advanced regeneration present immediately before the stand is harvested and the sprouting potential of the severed trees. For southern hardwoods, stems of advanced regeneration which are greater than one foot tall and severed trees less than ten inches diameter at breast height (dbh) are given the highest values.

Since hardwood managers must depend so heavily on advanced regeneration, a major question confronting them is how long the regeneration can be maintained in the understory. Johnson (1975) found that new Nuttall oak (Quercus nuttallii Palmer) seedlings remain in the understory for five to ten years. Any practice which would allow sunlight to reach these seedlings will probably improve their chances of survival and their growth. McGee (1968) found that height and leaf growth of Northern Red oak (Quercus rubra L.) decreased as the amount of light reaching the seedlings decreased.

When oak stems in the understory are plentiful but small, some form of partial cut may enable them to grow to a size large enough to be effective for regeneration (Sander 1972, Hurst and Myers 1982). Reduction of the overstory may accomplish this purpose in some cases, but most often it is the presence of shade-tolerant species in the mid- and lower canopies rather than the overstory that restricts light to the forest floor (Johnson and Krinard 1976, McKnight and Johnson 1980, Kellison et al. 1980). If desirable stems in the understory or ground flora are to benefit from sunlight passing through the overstory then this undesirable midstory and understory vegetation should be controlled (Johnson and Jacobs 1981, Loftis 1982). Undesirable stems should be killed in order to reduce sprouting and provide more growing space for the development of desirable stems (Graney and Rogerson 1985, Loftis 1985). The objective of this study was to determine if advanced oak regeneration could be maintained and its

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[2/] The authors are research technician and professor, Department of Forestry, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University. Contribution No. 6527 of the Mississippi Agricultural and Forestry Experiment Station.

Table 1.--Number of stems per acre, basal area, and mean dbh of trees greater than 1.0 inch dbh before treatments were installed (lowerstory, midstory, and overstory trees).

| | Number of Stems | | | Basal Area | | | $\bar{x}$DBH | | |
|---|---|---|---|---|---|---|---|---|---|
| | Inject | Inject/ Cut | Control | Inject | Inject/ Cut | Control | Inject | Inject/ Cut | Control |
| | -------No./acre------- | | | -------$ft^2$/acre------- | | | ----------in.--------- | | |
| Red Oaks[1/] | 95 | 95 | 185 | 66.0 | 36.5 | 32.8 | 7.6 | 4.6 | 4.1 |
| White Oaks[2/] | 18 | 23 | 48 | 16.8 | 30.7 | 21.2 | 12.3 | 14.6 | 6.5 |
| Desirable Species Other than Oaks[3/] | 135 | 130 | 125 | 13.7 | 11.0 | 11.8 | 3.1 | 3.0 | 3.0 |
| Undesirable Species[4/] | 377 | 330 | 337 | 28.2 | 37.1 | 50.1 | 2.6 | 3.1 | 3.4 |
| Total | 625 | 578 | 695 | 124.7 | 115.3 | 115.9 | 3.7 | 3.8 | 3.7 |

[1/] Red Oaks: Cherrybark, water, and willow oak

[2/] White Oaks: Post, swamp chestnut, and white oak

[3/] Desirable species other than oaks: Green ash and sweetgum

[4/] Undesirable species: Blackgum, deciduous holly, elm, hawthorn, hickory, ironwood, red maple, and red mulberry

growth enhanced prior to final harvest through control of undesirable midstory and understory vegetation.

## METHODS

The stand used for this study was located within the floodplain of Loakfoma Creek on the Noxubee National Wildlife Refuge in Winston County, Mississippi. This stand contained adequate advanced oak regeneration with water (Quercus nigra L.) and willow oak (Quercus phellos L.) being the primary oak species. The overstory was composed of mainly water oak, willow oak, and hickory (Carya species) while the midstory consisted of hickory and other less desirable, shade-tolerant species. Sweetgum (Liquidambar styraciflua L.) and green ash (Fraxinus pennsylvanica Marsh.) as well as many undesirable species were present in the lower story with the oaks (Table 1). Age of the overstory at the time the study was installed was 100 years. Site index (base age of 50 years) for water and willow oak is 100 feet (Baker and Broadfoot 1979).

Nine 1/5-acre plots were installed with six plots randomly selected for treatment of mid- and understory vegetation. Control plots were located apart from the treatment plots so as to avoid any edge effects. Treatments were assigned as follows:

(1) Inject only. All trees greater than 1.0 inch dbh that were undesirable species[3/] and did not contain at least one number three factory grade sawlog (USDA Forest Service 1981) were injected with glyposate. Desirable stems were left intact.

(2) Inject/Cut. Inject/Cut plots combined injection as above plus cutting of the remaining stems to the ground. Undesirable stems too small to be injected but three feet in height or taller were cut and stump sprayed with glyphosate. Desirable stems that did not contain at least one number three factory grade sawlog were cut to determine if a more vigorous sprout could be obtained.

(3) Control. Control plots received no herbicidal treatment; midstory and understory remained intact.

[3/] All oaks, sweetgum, green ash, and yellow-poplar were classed as desirable species for the purpose of this study. All other species were classed as less desirable due to their low commercial value or because they were off-site.

Injection and cutting plus stump spraying of undesirable stems was done in the fall of 1983. Cutting of desirable stems was done in the winter of 1983-84.

Each major plot contained two 1/100-acre circular subplots which were used to monitor changes in the number of stems of advanced regeneration. Growth response of individual oaks was measured on fifteen randomly located oaks within each major plot. These trees served as center of a 1/2-meter radius subplot in which all trees were flagged and measured for height by species.

## RESULTS AND DISCUSSION

### Pre-treatment Measurements and Observations

A diameter-limit cut, which occurred about 1945, left many of the overstory stems which are present today. As a result of this high-grading, stems are generally of poor quality. The resultant overstory has many holes in the main canopy, thus allowing substantial sunlight to pass through. Domination of the understory by shade-tolerant species was just beginning to occur when plots were selected.

Most of the undesirable stems greater than 1.0 inch dbh were removed by injection in the treated plots (Table 2). Inject/Cut plots also had the other desirable and oak species brought back to the ground. Also, undesirable stems less than 1.0 inch dbh and taller than 3 feet in the inject/cut plots were cut and stump sprayed. Some resprouting of undesirable stems occurred in the inject and inject/cut plots.

No statistical difference was found for the number of advanced oak stems present before treatments were installed (Table 3). Water and willow oak were the main oak species, with some cherrybark (Quercus falcata var. pagodifolia Ell.), swamp chestnut (Quercus michauxii Nutt.), and white oak (Quercus alba L.) also present. Most of these oaks were seedling-sized stems of various ages. Control plots had significantly more advanced stems of desirable species other than oaks present before treatments were installed. Species other than oak that were classed as desirable were green ash, sweetgum, and yellow-poplar. The majority of the desirable stems, other than oak, found initially in the control plots were sweetgum seedlings which germinated in 1983. The total number of advanced undesirable stems present before treatments were installed was high for all plots.

Table 2.--Number of stems per acre, basal area, and mean dbh of trees greater than 1.0 inch dbh after treatments were installed (lowerstory, midstory, and overstory trees).

| | Number of Stems | | | Basal Area | | | $\bar{x}$DBH | | |
|---|---|---|---|---|---|---|---|---|---|
| | Inject | Inject/ Cut | Control | Inject | Inject/ Cut | Control | Inject | Inject/ Cut | Control |
| | No./acre | | | ft$^2$/acre | | | in. | | |
| Red Oaks[1/] | 95 | 15 | 185 | 66.0 | 34.2 | 32.8 | 7.6 | 20.0 | 4.1 |
| White Oaks[2/] | 18 | 18 | 48 | 16.8 | 28.9 | 21.2 | 12.3 | 16.8 | 6.5 |
| Desirable Species Other than Oaks[3/] | 135 | 3 | 125 | 13.7 | 3.3 | 11.8 | 3.1 | 13.6 | 3.0 |
| Undesirable Species[4/] | 5 | 10 | 337 | 5.3 | 12.1 | 50.1 | 13.9 | 14.8 | 3.4 |
| Total | 253 | 46 | 695 | 101.8 | 78.5 | 115.9 | 5.6 | 17.2 | 3.7 |

[1/] Red Oaks: Cherrybark, water, and willow oak

[2/] White Oaks: Post, swamp chestnut, and white oak

[3/] Desirable species other than oaks: Green ash and sweetgum

[4/] Undesirable species: Blackgum, deciduous holly, elm, hawthorn, hickory, ironwood, red maple, and red mulberry

Table 3.--Total number of advanced stems per acre and mean height of stems before treatments were installed.

| | Oaks[1] | | Desirable Species Other than Oaks[2] | | Undesirable Species[3] | |
|---|---|---|---|---|---|---|
| | No./Acre | $\bar{x}$ Ht. | No./Acre | $\bar{x}$ Ht. | No./Acre | $\bar{x}$ Ht. |
| | | (cm) | | (cm) | | (cm) |
| Inject | 5,700 a[4] | 48.5 | 417 b | 187.0 | 4,017 a | 80.3 |
| Inject/Cut | 8,450 a | 42.2 | 500 b | 522.4 | 5,067 a | 130.4 |
| Control | 6,200 a | 31.3 | 4,517 a | 91.3 | 4,283 a | 73.2 |

[1] Oaks: Cherrybark, swamp chestnut, water, white, and willow oak

[2] Desirable Species Other than Oaks: Green ash, sweetgum, and yellow-poplar

[3] Undesirable Species: Beauty berry, black cherry, blackgum, box elder, deciduous holly, devil's walking stick, dogwood, elderberry, elm, hawthorn, hickory, honey locust, ironwood, loblolly pine, persimmon, red maple, red mulberry, sugarberry, and tree sparkleberry

[4] Values that are followed by the same letter indicate no statistical difference at the .05 level

Post-treatment Measurements and Observations

Effects on seedling stocking

The total number of oaks per acre decreased in all treatments (Tables 3 and 4). Although oaks and desirable species other than oaks were not intentionally sprayed with herbicides, some herbicide damage may have occurred in the inject/cut plots. Most of the seedling loss in all plots was due to the mortality of very small or very young seedlings. The production of viable acorns was low in the years following treatment of the plots; so the establishment of new oak seedlings was low. Thus, most of the oak stems in all plots were stems that were present before treatments were initiated.

For the first three year period of this study, mortality of oak seedlings was no higher in the control plots than in the treatment plots. However, as noted below, growth, especially in the third year, was lower in the control plots and it is expected that mortality will increase in those plots in the future. As indicated above, past cutting practices left this stand in a fairly open condition, which probably accounts for the amount of regeneration present. Had there been less light at the forest floor it is doubtful if seedling survival would have been so good.

The number of stems of desirable species other than oak increased in the inject and inject/cut plots. Most of this increase was a result of sweetgum germination in the second and third years after treatments were installed. After three years, stems of desirable species other than oaks had decreased by about one-half in the control plots. This decrease was caused primarily by mortality of many of the sweetgum seedlings which were less than a year old at the time the study was installed.

There was a slight increase in the number of undesirable stems in the treated plots. This was largely the result of new germination, but resprouting of some of the herbicide treated stems occurred also. The large increase in number of undesirable stems in the control plots was mainly the result of establishment of hickory seedlings in the second year following treatment.

Effects on Seedling Growth

After three years, there was no statistical difference in height growth of oak stems in the different treatments (Table 5). Analysis of height growth for all species was based on those seedlings which remained alive and showed no significant die-back during the three year post treatment period. Although there was no statistical difference in the mean height growth after three years, oak stems in the inject/cut plots showed the largest increase. These stems had already grown back to a height taller than before treatment. Oak seedlings in the inject plots showed dieback in the first year after treatment and a slight increase in height in the second year. It was not until the third year following treatments that oaks in the inject plots showed any appreciable gain in height. There was little

Table 4. Total number of advanced stems per acre three years after treatments were installed.

| Treatment | Oaks[1] | Desirable Species Other than Oaks[2] | Undesirable Species[3] |
|---|---|---|---|
| | No./Acre | | |
| Inject | 4,900 a[4] | 1,480 a | 4,550 a |
| Inject/Cut | 7,620 a | 2,280 a | 6,320 a |
| Control | 5,330 a | 2,830 a | 7,480 a |

[1]Oaks: Cherrybark, swamp chestnut, water, white, and willow oak

[2]Desirable species other than oaks: Green ash, sweetgum, and yellow-poplar

[3]Undesirable species: Beauty berry, black cherry, blackgum, box elder, deciduous holly, devil's walking stick, dogwood, elderberry, elm, hawthorn, hickory, honey locust, ironwood, loblolly pine, persimmon, red maple, red mulberry, sugarberry, and tree sparkleberry

[4]Values that are followed by the same letter indicate no statistical difference at the .05 level.

Table 5.--Mean height and height growth of advanced stems after treatments were installed.

| Treatment[1] | 1984 | 1985 | 1986 | 1983-84 | 1983-85 | 1983-86 | 1985-86 |
|---|---|---|---|---|---|---|---|
| Oaks | | | | | | | |
| | $\bar{x}$ HT (cm) | | | $\bar{x}$ HT Growth (cm)[3] | | | |
| Inject | 48.2 | 48.9 | 51.7 | -0.3 a[4] | 0.4 a | 3.2 a | 2.8 b |
| Inject/Cut | 25.2 | 35.3 | 48.6 | -17.0 b | -6.9 a | 6.3 a | 13.2a |
| Control | 32.0 | 32.2 | 33.0 | 0.7 a | 0.9 a | 1.8 a | 0.9 b |
| Desirable Species Other Than Oaks[2] | | | | | | | |
| Inject | 187.3 | 189.7 | 190.0 | 0.3 a | 2.7 a | 3.0 a | 0.3 b |
| Inject/Cut | 49.8 | 81.8 | 105.4 | -472.6 b | -440.6 b | -417.0 b | 23.6a |
| Control | 106.7 | 108.7 | 112.1 | 15.4 a | 17.3 a | 20.8 a | 3.5 b |

[1]Oaks: Cherrybark, water, and willow oak

[2]Desirable species other than oaks: Green ash and sweetgum

[3]Trees which were listed as dead in any year were not included in the analysis of height growth.

[4]Values that are followed by the same letter indicate no statistical difference at the .05 level.

growth of oak stems in the control plots in the three years following treatment.

Height growth of stems of other desirable species followed essentially the same pattern as described above for oaks. Fastest growth was from sprouts in the inject/cut plots, but even after three years average height was less than before treatment. This difference may be partially explained by the fact that the stems of these species were much taller when they were cut than were the oaks. Desirable stems other than oak showed a slight increase in height growth in the inject plots. While some of the sweetgum stems found in the control plots exhibited some height growth, many of these stems had died by the third year after treatment. Most of the growth of desirable stems other than oaks in the control plots was by green ash stems. Many of the green ash stems in the control plots were taller than other stems in the understory.

## CONCLUSION

Based on the preliminary results of this study the following tentative conclusions can be drawn:

1. Removal of midstory and understory competition appears to be a feasible way to maintain advanced regeneration of desirable species, especially oaks, and to promote their growth prior to the final harvest cut.

2. Response of suppressed oaks and other desirable species to release may be slow. The indications are that at least three years will be required for a significant response.

3. After removal of undesirable midstory and understory stems, best development of suppressed desirable seedlings may be obtained by severing them near ground line. The resultant sprouts are very vigorous and grow much faster than uncut stems. Pre-cut heights are surpassed within three years. Also, the quality of the sprouts may be superior to that of uncut stems which tend to be flat-topped, crooked, or have multiple leaders.

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RESPONSE OF A SECOND-GROWTH NATURAL STAND

OF BALDCYPRESS TO VARIOUS INTENSITIES OF THINNING[1/]

J. R. Toliver, S. G. Dicke, and R. S. Prenger[2/]

Abstract.--The effect of crown thinning on natural second-growth baldcypress [Taxodium distichum (L.) Rich] trees was studied to determine responses as measured by growth in height, diameter, and volume three years after thinning. Twelve, 1/4-acre circular plots were established in a 63-year-old baldcypress-water tupelo (Nyssa aquatica L.) stand inside the Atchafalaya Basin near Bayou Pigeon, LA. Treatments consisted of thinning to approximately 180 sq ft, 140 sq ft, and 100 sq ft of basal area per acre and no thinning (control = 222 sq ft). Diameter and volume growth of individual trees increased as thinning intensity was increased, but height growth was not influenced. Total volume growth on a per acre basis was not significantly different among treatments. However, at the highest intensities of thinning (100 and 140 sq ft) this growth was distributed on fewer and larger trees. The data indicate that thinning second-growth baldcypress trees will increase growth and quality of the larger more valuable trees.

## INTRODUCTION

Baldcypress has been a commercially important tree in the South since colonial times. In the early 1900's, vast stands of virgin baldcypress formed the backbone of Louisiana's lumber industry and allowed her to lead the nation in cypress lumber production from 1900-1920 (Burns, 1980). By 1925, the majority of the virgin baldcypress had been cut and 10 years later the supply was virtually exhausted. A USDA forest survey estimate indicated that by 1934, 1.6 million acres of baldcypress had been cutover (Norgress, 1947).

Current production in the United States is less than 200 million bd ft per year Williston et al., 1980). However, the total volume of standing cypress, primarily second-growth, is impressive. According to Williston et al. (1980), growing stock on commercial forest land in the U.S. totals approximately 5.5 billion cu ft. About 19.8 billion bd ft of sawtimber is available, of which 36 percent is in trees 17 inches dbh or larger. Louisiana and Florida contain more than half of this volume. Data obtained in a USFS inventory (Rosson and Bertelson, 1986) indicate 5.2 billion bd ft of cypress sawlog growing stock in Louisiana. Eighty-three percent of this growing stock is in the South Delta Louisiana Parishes of which 70 percent of the trees are less than 11 inches dbh. Thus, in Louisiana numerous densely stocked stands exist and appear to be in need of thinning. It is not uncommon for these natural stands of 60 to 70-year-old cypress to have 500-700 trees per acre, 200-300 sq ft of basal area per acre and average 7-8 inches in diameter at 18 inches above butt-swell.

Quite often the merchantable trees are cut by diameter-limit cutting practices (12 to 16-inch minimum) resulting in high-grading whereby numerous smaller and poorer quality trees are left standing. Few, if any, stands are properly managed.

Very little research has been accomplished in second-growth baldcypress stands and knowledge of optimum silvicultural practices is limited. For example, will these densely stocked stands respond to release by thinning and, if so, what is the proper stocking and density to maximize growth of high-quality cypress trees? Therefore, the objective of this study was to investigate the magnitude in growth of 63-year-old baldcypress trees when thinned to three levels of stand basal area per acre.

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1/ Paper presented at Fourth Biennial Southern Silvicultural Conference, Atlanta, GA, Nov. 4-6, 1986.

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## METHODS AND PROCEDURES

### Description of the Study Area

A natural stand of baldcypress/water tupelo was selected within the Atchafalaya Basin near Bayou Pigeon in Iberville Parish, Louisiana. The area consists of level clayey soils of the Fausse series that are characteristic of the backswamps and depressions within the Basin floodway. These soils are high in fertility and generally contain adequate amounts of moisture throughout the year. The site is subject to prolonged flooding one or more times each year, generally during the months of December through July but is not under constant water (Prenger, 1985).

Estimated virgin timber volume in 1908 was approximately 5553 bd ft per acre of which 86 percent was baldcypress and the remaining water tupelo. These volumes were rather low for virgin baldcypress stands and indicate that the trees were probably growing in isolated patches. The timber was logged and skidded by pull-boat from 1909-1914 (File information, Williams, Inc., Patterson, LA, present owners).

The stand is assumed to have originated as a result of seed-fall from the virgin trees. Annual ring counts taken in 1980 from 14 dominant and codominant trees indicated the mean age of the stand to be 63 years, which indicates the stand originated shortly after the virgin timber was harvested.

### Initial Measurements and Study Design

The study was initiated in the fall of 1980. Twelve 1/4-acre circular plots were randomly established in the stand. A 1/8-acre measurement plot was established within each major plot. All trees in the measurement plots were numbered with an aluminum tag nailed approximately 18 in. above butt swell (normal diameter).

Original measurements taken on the trees were diameter (inches) at the nail and total height (feet). Crown class (dominant, codominant, intermediate, and suppressed) was determined for each tree according to Smith, 1962. This information was used to determine the basal area and number of trees for each of the 12 plots. Then the plots were assigned to blocks according to their similarity in total basal area. This was done to insure that each thinning treatment could be randomly assigned within a low (188-206 sq ft/a), mid (207-222 sq ft/a) and high (246-259 sq ft/a) basal-area block.

One of four thinning treatments was randomly applied to a plot with a block. Treatments consisted of thinning to basal areas of approximately 180 sq ft/a, 140 sq ft/a, 100 sq ft/a and no thinning (control, 220 sq ft/a). Trees were marked to be cut or left based on species and potential for high quality sawtimber if left for at least 15-20 years. A crown thinning, crop-tree approach, was performed in December, 1980. High quality cypress trees were favored and surrounding trees were removed. Trees were first removed from the general level of the crown canopy and then down into lower crown classes until the desired basal area was achieved. Cutting was performed with chainsaws and the cut trees were left laying on the ground.

### Measurements and Calculations 3 Years After Thinning

Measurements were taken in the fall of 1983, three growing seasons after the thinnings were completed. Total height and normal diameter of the trees was measured. Height and diameter growth of each tree was calculated for the three-year period of growth.

Individual tree cubic foot volumes, inside bark, were calculated before and after thinning treatments were applied. Volumes were generated by using the following cypress volume equation:

Volume = $.0036 \times D^{1.74618} H^{1.07498}$ where D = diameter 18 inches above butt swell (inches), H = total height (feet), Parresol (1983).

Analysis of variance were calculated with Statistical Analysis System (SAS) procedure GLM and the DUNCAN option (SAS Institute, Inc. 1982).

## RESULTS AND DISCUSSION

### Initial Stand Characteristics

The second-growth stand was found to be densely stocked with an average of 604 trees per acre. Baldcypress made up 83 percent of the stand by stems, basal area, and volume per acre, and water tupelo constituted the remaining trees (Table 1). It is interesting to note that the virgin stand included approximately the same ratio by volume in 1908 (86% cypress to 14% tupelo).

Table 1. Characteristics of a natural second-growth stand of baldcypress/water tupelo in the South Delta region of Louisiana.

| Species | Trees/ acre | Normal diam. | Ht. | Basal area | Vol. |
|---|---|---|---|---|---|
| | | in. | ft. | $ft^2/a$ | $ft^3/a$ |
| Cypress | 501 | 7.7 | 63 | 180 | 6507 |
| Tupelo | 103 | 8.4 | 62 | 42 | 1332 |
| All trees | 604 | 7.8 | 63 | 222 | 7839 |

The diameter distribution, similar to a normal bell-shaped curve, was indicative of an even-aged stand. Over 50 percent of the trees

were cypress, less than 9.0 inches in diameter, and classified in the intermediate and suppressed crown class categories (Table 2). However, 31 percent of the stand was made up of codominant and dominant cypress trees (188/acre) ranging from 10-15 inches in diameter. These larger cypress trees averaged 11.0 inches in diameter and 79 feet tall and provided the basis for the crown thinning (Table 2).

Table 2. Mean density, diameter, and height, by crown class of a second-growth stand of baldcypress/water tupelo in the South Delta region of Louisiana.

| Crown class | Density (trees/acre) | | Diameter (inches) | | Height (feet) | |
|---|---|---|---|---|---|---|
| | Cyp | Tup | Cyp | Tup | Cyp | Tup |
| Dominant | 14 | 1 | 12.0 | 14.6 | 80 | 73 |
| Co-Dom. | 174 | 39 | 10.0 | 10.0 | 78 | 68 |
| Intermed. | 101 | 32 | 7.4 | 8.2 | 65 | 66 |
| Suppressed | 212 | 31 | 5.6 | 6.2 | 48 | 49 |

## Stand Characteristics After Thinning

Due to the nature of the stand and the thinning method applied much of the cutting was done within the condominant and intermediate cypress crown classes. As thinning intensity was increased more of the lower crown class trees were eliminated including many suppressed. Water tupelo was cut to favor cypress thus it became a small component on the plots particularly at the 140 and 100 basal area thinning intensities (Table 3). After thinning, mean total plot basal area per acre was 221, 179, 142, and 101 sq ft/a for the four treatments and cypress made up 83, 84, 94, and 93 percent of the basal area respectively. Due to the major interest in producing high quality baldcypress sawlogs and the low component of water tupelo left after thinning, only the growth response of cypress will be addressed in this paper.

## Three-year Growth Response of Baldcypress

### Height Growth

No significant differences in mean height growth were found among treatments or among crown classes. In fact height growth averaged less than 1 foot. It appears that height growth was not stimulated by thinning and the stand height is increasing at a very slow rate. Williston et al., 1980 refer to a 41-year-old cypress plantation in Tishomingo County, Miss. in which the dominants averaged 69 feet tall and to a thinned cypress stand near Abbeville, Miss. in which the crop trees averaged 119 feet tall at roughly 100 years of age. The average height of the dominant and codominant trees in this study was 79 feet at 66 years. Assuming the sites are comparable the trees in this study have not reached their maximum height thus the potential for increased height growth is present.

Table 3. Mean numbers of trees left after thinning a second-growth stand of bald-cypress/water tupelo to various intensities of basal area.

| | Thinning intensity (ba/acre) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Control (220) | | 180 | | 140 | | 100 | |
| Crown class | Cyp | Tup | Cyp | Tup | Cyp | Tup | Cyp | Tup |
| | - - - - - - trees/acre - - - - - - | | | | | | | |
| Dom. | 5 | 0 | 5 | 0 | 11 | 0 | 29 | 0 |
| Co-dom. | 189 | 16 | 128 | 27 | 144 | 13 | 93 | 3 |
| Interm. | 83 | 45 | 77 | 19 | 80 | 5 | 19 | 6 |
| Supr. | 229 | 67 | 197 | 27 | 83 | 40 | 51 | 29 |
| TOTAL | 506 | 118 | 407 | 73 | 318 | 58 | 192 | 38 |

An underlying objective of this study was to determine if the remaining suppressed, intermediates, and weaker codominants would respond to thinning. If these lower crown classes would respond then the stand could be managed as a two storied stand. The larger trees could be harvested and the second story could be nurtured into merchantable sawlog trees. Height growth would be important in recovering the vigor of the lower crown class trees. However, the 3-year data indicates very little if any response in height growth of the trees. On the other hand 3 years is probably not enough time to expect much of a response.

### Individual Tree Diameter and Volume Growth

In general diameter growth increased with an increase in thinning intensity (Table 4). With the exception of the codominants those trees on plots thinned to 100 basal area more than doubled their diameter growth over the unthinned trees. Diameter growth of the codominants in the 100 basal area plots was one-third greater than in the control. It is interesting to note that the suppressed and intermediate trees on the 100 basal area thinned plots grew at approximately the same rate as the dominants and codominants on the unthinned plots. Although there was very little difference in diameter growth among thinning treatments within a given crown class, thinning alone significantly increased diameter growth over the control (unthinned). The lack of significant differences among thinning treatments within a crown class may be related to the method of thinning. The best trees were always chosen and the adjacent competition was removed. However, we expect the trees in the lower basal area plots to sustain their improved growth over a longer period of time whereas the

crowns of the trees on the 180 basal area plots will close quicker and diameter growth will decrease. Thus given more time the difference in diameter growth among treatments will probably become more prominent.

Table 4. Mean diameter growth of 65-year-old baldcypress trees 3-years after thinning.

| Crown Class | Thinning intensity (ba/acre) Control (220) | 180 | 140 | 100 |
|---|---|---|---|---|
| | - - - Dia. growth (inch) - - - | | | |
| Dominants | .30a[1] | .50a | .58a | .60a |
| Codominants | .26b | .39a | .35ab | .42a |
| Intermediates | .09a | .05a | .13a | .23a |
| Suppressed | .02b | .08b | .06b | .26a |
| Mean | .13c | .18bc | .23b | .39a |

[1]Means followed by the same letter within rows are not significantly different ($P \leq 0.05$) according to Duncan's New Multiple Range Test.

Volume growth per tree followed the same trend as diameter growth. Mean volume growth for individual trees was 0.48, 0.65, 0.85, and 1.44 cubic feet respectively for the Control, 180, 140, and 100 basal area thinning intensities. There were no significant differences among thinning treatments within crown classes. However, as thinning intensity increased there was a pattern of increased volume growth within all crown classes.

## Stand Growth

When individual tree volume growths were expanded to stand volume growth on a per acre basis no significant differences were found among the four thinning treatments. Cubic foot volume growth per acre was 241, 255, 265 and 265 for the control, 180, 140 and 100 basal area thinnings. However, the growth was distributed on fewer and larger trees on the lower basal area plots. Thus, these trees should become larger and higher quality merchantable trees in less time. Stand characteristics 3 years after thinning are presented in Table 5.

## CONCLUSIONS

Second-growth baldcypress trees responded to crown thinning at age 63 years. Three years after thinning, individual tree diameter and volume growth had increased with increases in thinning intensity; however, there was no change in height. Although not statistically significant, there was a trend of increased diameter and volume growth among thinning treatments within each of four crown classes.

Total volume growth over 3 years was not significantly different among thinning intensities. However, the volume growth was concentrated on fewer and larger trees on the more intensely thinned plots.

Table 5. Characteristics of a second-growth baldcypress/water tupelo stand 3 years after thinning to various intensities of basal area per acre.

| Thinning intensity | Basal area | Volume | Trees/ acre |
|---|---|---|---|
| | $ft^2/a$ | $ft^3/a$ | |
| 220 (control) | 189 | 7111 | 501 |
| 180 | 156 | 5573 | 394 |
| 140 | 138 | 5141 | 322 |
| 100 | 98 | 3693 | 184 |

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# A COMPARISON OF BIOMASS AND NUTRIENT CONTENT IN PIEDMONT AND COASTAL PLAIN BOTTOMLAND HARDWOOD STANDS[1]

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and D. R. Phillips[2]

Abstract.--Biomass and nutrient content (N, P, K, Ca and Mg) were examined in fully-stocked, even-aged 10-, 20, 40- and 60-year-old Piedmont and Coastal Plain bottomland hardwood stands. Aboveground biomass yields for the Coastal Plain sites were approximately double the Piedmont biomass values for the 10- and 20-year-old stands. Nutrient content was directly related to biomass yield and thus was greater for all Coastal Plain bottomland sites except the 40-year-old stands. Annual biomass accumulation for the 60-year-old stands did not differ significantly between provinces; however, N and P accumulation rates were 8.1 and 1.1 kg $ha^{-1}yr^{-1}$ for the Coastal Plain and 6.9 and 0.8 kg $ha^{-1}yr^{-1}$ for the Piedmont sites, respectively. The high nutrient accumulation rates of Coastal Plain bottomland hardwood stands indicate that greater nutrient removals and possible productivity declines may occur following intensive harvesting.

## INTRODUCTION

The Piedmont and Coastal Plain are two major provinces supporting hardwood forests in the southeastern United States. The southern Piedmont encompasses nearly 18 million ha within Virginia, North Carolina, South Carolina and Georgia. Roughly 64 percent of the total land area is commercial forest supporting over 1.27 billion tonnes of hardwood standing biomass (Bechtold and Phillips, 1983). Piedmont forests are a diverse mixture of hardwood species and mixed pine types occupying a spectrum of sites from dry upland slopes and ridges to rich bottomlands.

Bottomland hardwood forests are the most productive in the United States and cover an estimated 12.9 million ha on the Atlantic and Gulf Coastal Plains with Virginia, North Carolina, South Carolina, Georgia and Florida comprising 42 percent of the total (Langdon and others, 1981). These Coastal Plain forests are also a diverse mixture of hardwoods and hardwood-conifer associations that occur on the floodplains of major rivers originating in the Mountains, Piedmont and Coastal Plain. Sites typically have little topography and soils range from poor to well drained and from loam to silt loam in texture.

Piedmont and Coastal Plain hardwood forests are typically poorly stocked , are low in quality, and contain small diameter trees reflecting a history of high grading, agricultural use, fire and grazing (Smith and Linnartz, 1980; Kellison and others, 1981). Difficulties associated with managing mixed stands and poor market conditions for low quality trees have discouraged intensive management. Only recently has the potential of these forests been realized with the technological advances in harvesting and utilization systems and, new products made using hardwood fiber.

An increasing number of hardwood stands are being harvested and a larger portion of the trees are being utilized. Topwood, branches, small twigs and even leaves are often removed during whole tree harvesting (WTH) leaving behind very little residue. Whole tree harvesting of hardwood stands can increase utilization over 100 percent compared to conventional saw log harvesting (Phillips and Van Lear, 1984). However, because of the disproportionately high nutrient concentrations in topwood, small branches and foliage, large amounts of nutrients can be removed from the site (Francis, 1984; Messina and others, 1983; Megalos and others, 1986). Johnson and others (1982) stated that losses of N, P, K, and Ca after WTH were 2.9, 3.1 3.3 and 2.6 times more than those in saw log harvesting of a mixed hardwood stand. Utlimately, the amount of nutrients removed following intensive utilization will depend on the total biomass, the nutrient concentrations of the various tree components, and total nutrient content of the tree.

We undertook this study to compare the biomass and nutrient content of stands and species growing on Piedmont and Coastal Plain bottomlands and to determine whether differences existed among

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[1] Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, GA, November 4-6, 1986.

[2] Respectively Research Assistant and Professor, School of Forest Resources, North Carolina State University and Research Scientist and Project Leader, United States Forest Service, Southeastern Forest Experiment Station.

age classes and across regions.

## MATERIALS AND METHODS

Sixteen mixed, even-aged, fully stocked Piedmont and Coastal Plain hardwood stands in the 10, 20, 40 and 60-year-age classes on the bottomland site type were located. Stands were well distributed over each province and located on industrial, state, and private forestland in cooperation with members of the N. C. State Hardwood Research Cooperative. Vegetation was sampled in late summer or early fall to minimize the variation in moisture content and nutrient concentrations which can vary seasonally (Auchmoody and Grewling, 1979; Bowersox and Ward, 1977). Two replications of concentric sample plots were established around a randomly located plot center in each stand. Pulpwood and sawtimber trees (12.7 cm DBH) were destructively sampled on a 0.04-ha plot and saplings (2.5 - 12.4 cm DBH) were sampled on a 0.008 ha concentric circular subplot. Green weight of stems, branches and foliage was determined for all trees. Dry weight determinations were made using stem disks, branch disks and foliage subsamples following the methodology of Frederick and others (1979). Disk and foliage subsamples were selected for nutrient analysis from a minimum of three trees per 2.5 cm diameter class per species on each plot. Tree components (bole, branches, foliage, wood and bark) were systematically subsampled following procedures developed by Messina and others (1983).

Trees, shrubs and vines > 1 m tall and < 2.5 cm DBH were sampled on four randomly located 1.67 x 4.98 m subplots, one per quadrant as determined by random azimuths from plot center.

Understory vegetation (<1 m tall) was sampled on two randomly established transect lines consisting of twenty-five, 30.5 x 61.0 cm subplots spaced at 1 m intervals along each line originating from plot center. Composited samples were subsampled for biomass and nutrient analyses.

### Laboratory Procedures

Laboratory analyses followed standard procedures, with all tissue samples dried to a constant weight at 70 degrees C. Samples were ground in a Wiley mill to pass through a 0.85 mm mesh stainless steel screen. Total nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) were determined following a modified wet-ashing procedure (Parkinson and Allen, 1975). Nitrogen and P were determined by automated colorimetric methods on a Technicon AutoAnalyzer as the ammonium salicylate and phosphomolybdenum complexes, respectively. Potassium, Ca and Mg were determined by atomic absorption spectrophotometry. Samples were analyzed in the soils laboratory of the Department of Forestry at North Carolina State University.

## RESULTS AND DISCUSSION

### Species Composition

Sweetgum (Liquidambar styraciflua L.) was the dominant species on the bottomland site type in both provinces (Figure 1). Sweetgum comprised approximately 60 percent of the overstory composition. Additional dominant species occurring on the Coastal Plain in descending order of occurrence included cottonwood (COT) (Populus deltoides L.). red maple (RM) (Acer rubrum L.) and white oak (WO) (Quercus alba L.). Additional Piedmont species in descending order of occurrence included: water oak (WAO) (Quercus nigra L.), hickory (HK) (Carya spp.) and green ash (GA) (Fraxinus pennsylvanica Marsh.). Other species, individually comprising less than 3 percent of the total frequency accounted for about 16 percent of the total species occurrence in both provinces.

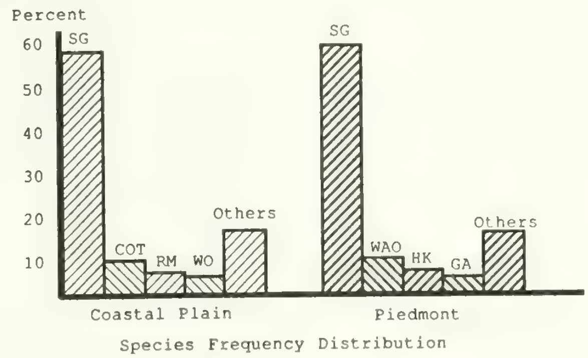


Figure 1. Overstory species composition of Coastal Plain and Piedmont bottomland hardwood stands. (Sweetgum, SG; Cottonwood, COT; red maple, RM; White Oak, WO; water oak, WAO; hickory, HK; green ash, GA)

### Aboveground Biomass

Total aboveground biomass yields for Coastal Plain 10 and 20 year-old stands were 45.8 and 142.1 Mg ha$^{-1}$ respectively at similar ages (Table 1). Piedmont forty year yields (255.7 Mg ha$^{-1}$) were significantly higher than Coastal Plain (217.3 Mg ha$^{-1}$) and not significantly different for both provinces in the 60-year age class (Figure 2.).

The exceptional yields for the 40-year-old Piedmont stands and decline at age 60 reflect a likely growth peak and optimal rotation age for biomass production close to age 40. The data for the Coastal Plain is less conclusive but suggests a longer rotation age, perhaps 60 years or more.

Coastal plain stands of all ages had a larger sapling component which accounted for some of the differences in total aboveground biomass. Understory vegetation biomass was a minor component except in the 10-year old Piedmont hardwood stands.

### Nutrient Concentration of Tree Components

The concentration of nutrients (N, P, K, Ca and Mg) in tree components in bottomland stands of

Table 1. Dry weight biomass of components, understory vegetation and total trees of Piedmont and Coastal Plain bottomland hardwood stands in the Southeastern United States.

| Age | Foliage | Branches | Bole | Saplings | Understory | Total Aboveground |
|---|---|---|---|---|---|---|
| | ----- | ----- | ----- | Mg $ha^{-1}$ | ----- | ----- |
| | | | Piedmont | | | |
| 10 | - | - | - | 15.0 | 7.5 | 22.5 |
| 20 | 2.6 | 22.6 | 32.6 | 18.0 | 2.5 | 78.3 |
| 40 | 4.8 | 73.6 | 171.0 | 5.3 | 1.0 | 255.7 |
| 60 | 2.7 | 82.6 | 154.8 | 3.5 | 0.8 | 244.4 |
| | | | Coastal Plain | | | |
| 10 | - | - | - | 42.6 | 3.2 | 45.8 |
| 20 | 1.8 | 27.4 | 84.9 | 27.1 | 0.9 | 142.1 |
| 40 | 5.2 | 56.0 | 144.2 | 9.0 | 2.9 | 217.3 |
| 60 | 6.2 | 50.4 | 164.0 | 15.9 | 1.5 | 230.0 |

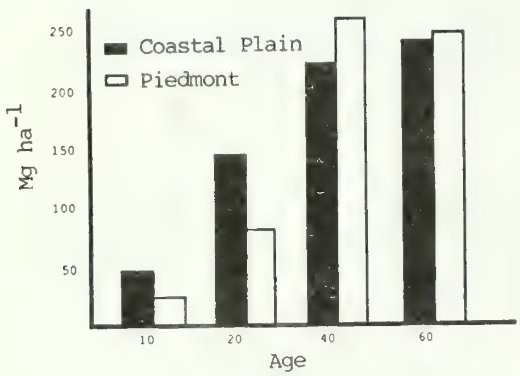


Figure 2. Total aboveground dry biomass for Coastal Plain and Piedmont hardwood stands

both provinces was generally greatest in foliage and decreased in the order foliage > stem bark > branches > stemwood. (Megalos and others, 1986; Phillips, 1985; and Messina, 1983) (Table 2). Nutrient content is a function of the amount of biomass and its distribution among these components. At early stand ages a greater proportion of biomass is contained in nutrient-rich foliage and branches. As a stand develops, the bole component becomes the largest biomass source and ultimately comprises the largest aboveground nutrient pool.

Nutrient Content of Stands

Nutrient content of bottomland stands was directly related to biomass yield (Table 1). The 10- and 20-year-old Coastal Plain stands contained approximately twice the N, P, K, Ca and Mg levels of similar aged Piedmont stands (Table 2). At age 40, Piedmont bottomland total biomass yields were nearly 18% greater than comparable Coastal Plain stands, yet nutrient contents were disproportionately lower for the elements N, P, K and Mg. Nitrogen, P, K and Mg levels for the 40-year-old Piedmont stands averaged only 2.5% greater than Coastal Plain nutrient values. Calcium was the only nutrient that exhibited a direct relationship with biomass yields across both geographic regions. At age 60, there were large differences in nutrient content which reflected proportionate differences in nutrient concentrations.

The Coastal Plain bottomland yield (238 Mg $ha^{-1}$) was 3 percent lower than that of the Piedmont (244.3 Mg $ha^{-1}$) (Table 1). However, this represented greater nutrient content levels for the Coastal Plain of 15 percent for N, 40 percent for P, 23 percent for K, 34 percent for Mg and decrease of 5 percent for Ca. The average nutrient concentrations for the Coastal Plain were much greater than those of similar aged Piedmont stands with the single exception of Ca.

Coastal Plain foliage and sapling dryweight values for 60 year-old stands were 2 and 4 times greater, respectively, than Piedmont foliage and saplings yields.

The relative abundance and nutrient "richness" of foliage and juvenile sapling material in the Coastal Plain stands comprise a significant portion of the total nutrient content of the stand and partially explains the large difference in nutrient contents between provinces.

Annual Accumulation and Elemental Utilization

Although this study represents a "point in time" view of nutrient content and biomass yield of bottomland stands, the comparison of nutrient accumulation rates between provinces can provide insight into the relative efficiency of biomass production. Annual biomass accmulation rates for

Table 2. Nutrient content of Piedmont and Coastal Plain hardwood stands in the Southeastern United States.

| Age | Foliage | Branches | Bole[1] | Saplings | Understory Vegetation | Total Aboveground |
|---|---|---|---|---|---|---|
| | kg ha$^{-1}$ | | | | | |
| | | | **Piedmont** | | | |
| | | | Nitrogen | | | |
| 10 | - | - | - | 51 | 22 | 73 |
| 20 | 23 | 25 | 18 | 47 | 11 | 124 |
| 40 | 82 | 194 | 178 | 33 | 6 | 492 |
| 60 | 37 | 192 | 166 | 15 | 5 | 415 |
| | | | Phosphorus | | | |
| 10 | - | - | - | 6 | 3 | 9 |
| 20 | 2 | 3 | 2 | 4 | 1 | 12 |
| 40 | 7 | 27 | 28 | 4 | 1 | 67 |
| 60 | 3 | 22 | 19 | 2 | 1 | 47 |
| | | | Potassium | | | |
| 10 | - | - | - | 30 | 13 | 43 |
| 20 | 10 | 19 | 17 | 29 | 7 | 82 |
| 40 | 34 | 127 | 187 | 19 | 6 | 373 |
| 60 | 16 | 153 | 165 | 9 | 4 | 347 |
| | | | Calcium | | | |
| 10 | - | - | - | 78 | 34 | 112 |
| 20 | 15 | 63 | 64 | 98 | 18 | 258 |
| 40 | 45 | 323 | 413 | 50 | 5 | 836 |
| 60 | 29 | 579 | 597 | 50 | 11 | 1266 |
| | | | Magnesium | | | |
| 10 | - | - | - | 12 | 5 | 17 |
| 20 | 5 | 6 | 6 | 12 | 3 | 32 |
| 40 | 14 | 38 | 53 | 5 | 1 | 111 |
| 60 | 6 | 37 | 47 | 4 | 1 | 95 |
| | | | **Coastal Plain** | | | |
| | | | Nitrogen | | | |
| 10 | - | - | - | 141 | 17 | 158 |
| 20 | 25 | 54 | 79 | 42 | 11 | 211 |
| 40 | 101 | 158 | 160 | 20 | 19 | 458 |
| 60 | 93 | 162 | 186 | 36 | 10 | 487 |
| | | | Phosphorus | | | |
| 10 | - | - | - | 23 | 3 | 26 |
| 20 | 6 | 8 | 12 | 6 | 1 | 33 |
| 40 | 9 | 26 | 29 | 3 | 3 | 70 |
| 60 | 7 | 31 | 22 | 4 | 2 | 66 |
| | | | Potassium | | | |
| 10 | - | - | - | 110 | 9 | 119 |
| 20 | 15 | 39 | 96 | 35 | 4 | 189 |
| 40 | 44 | 115 | 168 | 13 | 19 | 359 |
| 60 | 45 | 116 | 232 | 27 | 6 | 426 |
| | | | Calcium | | | |
| 10 | - | - | - | 140 | 23 | 163 |
| 20 | 19 | 97 | 170 | 103 | 7 | 396 |
| 40 | 78 | 317 | 261 | 38 | 6 | 700 |
| 60 | 66 | 321 | 734 | 71 | 14 | 1206 |
| | | | Magnesium | | | |
| 10 | - | - | - | 21 | 3 | 24 |
| 20 | 8 | 14 | 33 | 13 | 1 | 69 |
| 40 | 16 | 47 | 35 | 5 | 5 | 108 |
| 60 | 22 | 61 | 28 | 14 | 2 | 127 |

[1] 10 cm diameter-outside-bark.

both province averaged 4.0 Mg $ha^{-1}$ $yr^{-1}$, however, N and P accmulation rates were 8.1 and 1.1 kg ha $yr^{-1}$ for the Coastal Plain and 6.9 and 0.8 kg ha $yr^{-1}$ for the Piedmont sites, respectively. These relatively small differences in nutrient accumulation rates could result in the increased uptake of 72 kg of N and 19 kg of P in Coastal Plain stands over a 60 year rotation compared to Piedmont stands with comparable yields. The increased uptake of nutrients in Coastal Plain bottomland stands should be of particular interst to forest managers and researchers concerned with nutrient removals following intensified harvesting. Higher stand nutrient content may suggest increased susceptibility to productivity declines following intensive harvesting.

When evaluating the nutrient content and biomass of various stands it is important to have a common method of comparison. This study used the efficiency ratio concept from ecological studies and applied it to nutrient utilization. Nutrient utilization is defined as the ratio of nutrient content per dry weight of biomass kg $Mg^{-1}$. Listed below are data from our 60-year-old bottomland stands and a loblolly pine stand for baseline comparison (Table 3).

Table 3. Nutrient utilization efficiency rates for various stand types in the southern United States.

| Stand Type | N | P | K | Ca | Mg |
|---|---|---|---|---|---|
| | | | Nutrient | | |
| | ----------Kg $Mg^{-1}$---------- | | | | |
| Coastal Plain Bottomland 1/ | 2.0 | 0.3 | 1.8 | 5.4 | 0.5 |
| Piedmont Bottomland 2/ | 1.7 | 0.2 | 1.4 | 4.8 | 0.4 |
| Loblolly Pine 3/ | 1.1 | 0.1 | 0.9 | 2.1 | 0.3 |

1/ Messina, 1983

2/ Megalos, 1986

3/ Cole and Rapp, 1981

Both bottomland hardwood stands rank well above the nutrient efficiency of loblolly pine, for all nutrient elements with P and Ca showing the greatest differences.

## CONCLUSIONS

Southeastern bottomland forests are very productive and complex ecosystems. Many variables including site, species mix, stand structure, age and other factors will influence biomass and nutrient accumulation and distribution. Based on these data, Coastal Plain and Piedmont bottomland stands show many similarities in these parameters but also disparities which could have very important implications to management. The differences in nutrient content, distribution and utilization efficiency with these two stand types deserve recognition and further elucidation if these forests are to be managed most effectively.

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# SWAMP WHITE OAK RESPONSE TO VARIOUS LEVELS OF NITROGEN AND PHOSPHORUS - SURFACE APPLIED[1]

(ABSTRACT)

John R. Seifert and Phil E. Pope[2]

In 1985, ten levels of nitrogen with and without phosphorus was surface applied to two year old swamp white oak seedlings. Nitrogen (as ammonium nitrate) was applied at rates from 0 to 200 lbs per acre and phosphorus at the rate of 90 lbs per acre was applied to three nitrogen treatments. Chemical weed control was applied in the spring of each year. Soil analysis was performed in 1985 before and after treatment and leaf tissue analysis was performed after treatment in 1985. Soil and leaf analysis was again performed in 1986 to evaluate second years effects. Results will include diameter growth, height and increment growth, soil nutrients and leaf tissue.

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# THE EFFECT OF THINNING AND PRUNING ON THE GROWTH OF PLANTED LOBLOLLY PINE STANDS [1/]

Daniel J. Leduc and Boris Zeide [2/]

Abstract.--A study was begun in 1971 to determine the effects of four levels of thinning (initially 40, 60, 80, and 100 and subsequently 30, 50, 70, and 90 square feet of basal area per acre) and three levels of pruning (live crowns equal to 25, 40, and 55 percent of total tree height) on the growth of a plantation of loblolly pine (*Pinus taeda* L.). In 1984 the sixth measurement of this stand was completed and the data was analyzed for the effects of thinning, pruning, blocking, and treatment-blocking interaction. These factors had no effect on height growth. Diameter growth increased with decreasing density and increasing live crown ratio, and in general, the accumulated cubic foot volume (present volume at the latest measurement plus all previously removed volumes) and maximum mean annual increment increased with both density and crown ratio.

## INTRODUCTION

To maximize the productivity of intensively managed southern pine forests, they have to be maintained at optimal density and pruning levels until the age when the maximum mean annual increment of desired products is reached. The search for these optimal levels, particularly that of density, has been a major aspiration of foresters, empirically pursued since the inception of this profession. The first solution which was found was that productivity increases with the number of trees and reaches a maximum in undisturbed stands with the greatest possible tree number and complete crown closure. This answer emerged over 200 years ago in Denmark (Mar:Moller 1954) from a comparison of overcut and high-graded forests with closed and productive ones. However, during the nineteenth century a reversal of this result was proposed. It was felt that within reasonable limits, volume increment (of stems) was considered to be approximately proportional to the degree of thinning, that is, to the decrease in tree number. The contradiction between these two answers is not as sharp as it seems since the new concept was not developed in high-graded stands. Rather, it came from long-term observations of more or less evenly spaced best (crop) trees, selected at an earlier age and relieved from excessive competition stress during subsequent development by frequent thinning of neighboring trees. The most authoritative support of the concept came from Schwappach (1911) who, based on the results of 30 years of observations on 40 permanent sample plots established in Prussian beech stands, showed that heavy thinning increased the volume increment up to 16 percent.

The next development can be attributed to Wiedemann (1932), Schwappach's successor in charge of the Prussian Forest Experiment Station. Using 50-year observations of the same beech and other stands, he demonstrated that, within a wide range of density, productivity is independent of thinning intensity (and tree number). These results

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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have been confirmed in many countries (Mar:Moller 1954, Tkachenko 1955, Georgievsky 1957, Wiedemann 1960, Carbonnier 1976, Daniel and others 1979, Drew and Flewelling 1979), and at present the majority of foresters believe that thinning can redistribute the increment from smaller to larger stems but not increase its amount. This opinion is not a consensus (Assmann 1970), and considerable effort, in the form of thinning studies, is presently directed toward the empirical search for optimal density (Clutter and others 1983).

The only reliable way to find the best levels of density and pruning and the age of their maximum mean annual increment are long-term observations of permanent plots thinned to various density levels. Such studies are a standard method of growth research, particularly in productive loblolly pine forests (Williston and Dickerson 1968, Van Hooser 1970, Burton 1981, Clason and Cao 1985).

One such study was established 16 years ago in a 12-year old loblolly pine (Pinus taeda L.) plantation situated four miles southeast of the University of Arkansas at Monticello. This work was done by James D. Burton of the Southern Forest Experiment Station and described in Study Plan 1107-1.21 (Burton 1968) and Establishment Report FS-SO-1115-4.2 (Burton 1971). The original design included four levels of thinning (initially 40, 60, 80, and 100 and subsequently 30, 50, 70, and 90 square feet per acre) and three levels of pruning (live crown lengths equal to 25, 40 and 55 percent of total height). Each combination had three replications. Four additional plots were established as check plots where one of the four thinning treatments was applied without pruning. The total number of plots was 40. Each plot had a gross size of 132 X 132 feet. The measurement plot, 66 X 66 feet, lay in the center of the gross plot. Thus each study plot consisted of a 0.1 acre measurement plot surrounded by an isolation zone one chain wide.

Since 1981 the study has been maintained by the Department of Forest Resources of the University of Arkansas at Monticello in cooperation with the Forest Service and the Georgia-Pacific Corporation. The present study plan (Zeide 1981) is a continuation of the previous work and is intended to maintain the plots and carry out periodic measurements of the plots.

There were a few changes in the study plan since it was originally conceived. In 1981, after consultation with the Forest Service, pruning, which actually had not been done since 1974, was formally deleted from the study plan. It was felt that pruning had only a restricted practical application because of its prohibitive cost (Zeide 1981). In 1984 five control plots were established in the adjacent untreated part of the same plantation as the original 40 treated plots. At the same time, stem analysis was done using 25 of the trees to be removed by the 1985 thinning. These trees were selected to represent all four thinning levels and the control plots as they existed at age 27.

## METHODS

### Inventory methods

The same basic inventory methods were used for all of the six measurements of the study area. The diameters of all trees located in the buffer strip were taken to calculate basal area. The actual study plot trees were measured for diameter, height to the first live branch, total height, and the height to each 2-inch diameter class outside bark (so that volume could be calculated by the height accumulation method developed by Grosenbaugh (1954)). Additionally, the inventory in 1984 included the measurement of crown radius in the longest direction and 90 degrees to it, and the diameters at one and three feet above the ground. Diameter at breast height (the paint mark set by previous inventories rather than an actual 4.5 feet from tree base) was measured with a diameter tape to the nearest 0.1 inches, crown width was measured with a tape measure, and the diameters at one and three feet above the ground were measured with calipers.

All height measurements were taken with a Zeiss teledendrometer because this is both an accurate instrument and the same instrument used in all previous inventories. To achieve measurement consistency, we used the procedure described by the Forest Service technician who worked on all previous inventories. Measurement accuracy was improved by calibrating the dendrometer for instrument bias in 1984 and applying the correction to the recorded data.

### Selection of trees to be thinned

Size and form of trees were the chief criteria used to select trees for removal. Bent trees and trees with cankers or broken tops were always selected against when there was sufficient basal area to permit their removal. However, even low quality trees were not removed when the basal area did not meet the study guidelines.

### Methods of data treatment

#### Volume calculation

Height accumulation was used to calculate the volume of all sampled study plot trees. A discussion of the theory and general application of this technique is provided by Grosenbaugh (1954), Lohrey and Dell (1969), and Lohrey (1973). While the details of this method will not be explained, some background on our particular application of it is necessary.

With the technique of height accumulation, volume is calculated as a linear function of height, the sum of the heights to each successive two inch taper step, and the accumulation of the previous sum to the upper two inch taper step. The form of this function is shown by:

$$\text{VOLUME} = A(H') + B(H) + C(L) \tag{1}$$

where:
VOLUME is volume in any selected units; A,B, and C are calculated coefficients; L is the sum of section lengths or tree height; H is the sum of the heights to the top of each section; and H' is the sum of the sum of the heights to each section.

The coefficients used in this calculation are determined from geometric formulae and are based on the volume units, the size of the taper step, and the ratio of the diameter inside bark (dib) to diameter outside bark (dob) when inside bark volume is desired. For the purposes of this paper a dib/dob ratio of 1.0 was used since the volume of interest was total outside bark volume in cubic feet. The coefficients of equation 1 for this ratio are as follows: A = 0.0436, B = 0.0000, and C = 0.0073. In addition to these coefficients, HTACCU, the FORTRAN program used to calculate volume, allows a minimum DBH and top diameter to be entered for each volume calculated. To obtain total cubic foot volume outside bark, zeros were entered for each of these variables.

During the last two measurements for which we were responsible, all study plot trees were measured with sufficient detail to calculate volume. However, the previous four inventories of this study obtained detailed information for only 12 trees per plot. For the remaining trees only the diameters were recorded. In order to provide a comprehensive volume growth summary, an equation which would allow us to predict volume from known data was needed. For this purpose several functions for calculating volume based upon diameter and other stand conditions were investigated. A simple log-linear model was settled on because of the apparent goodness-of-fit of this model, and the multicollinearity problems which developed in the more complex models. Multicollinearity causes parameter estimates to be unstable and to have high standard errors (SAS Institute, 1982). Explicitly, the model used was:

$$\text{Ln(volume)} = \text{Ln}(A) + B(\text{Ln(dbh)}) \tag{2}$$

where:

A and B are coefficients calculated for each type of stem volume and age; and Ln is the natural logarithm function.

Since logarithmic transformation introduces bias when the original dependent variable is not lognormally distributed, an adjustment factor was calculated for each equation by finding the average ratio of actual to predicted volume. This factor was used to adjust all predicted volumes. The equation coefficients, adjustment factors, and other relevant statistics are presented in Table 1.

Volume calculated by height accumulation was checked by comparing it to standard volume tables and to the volume calculated using 17 stem analyzed trees from this study.

Analysis of variance

As suggested by our study plan (Zeide, 1981), stand volume was studied as a function of blocking, thinning, pruning, and the thinning-pruning interaction. This analysis was done both with and without including our new control plots. However, in both cases 3 of the 40 treated study plots were excluded since they were severely damaged by previous ice storms (Burton 1981b) and no longer represented their intended treatments. The excluded plots were all pruned to a live crown ratio of 25 percent. One plot had a density of 70 square feet of basal area and the other two had 90 square feet of basal area. To study the effect of the above-mentioned

Table 1. Coefficients used to estimate total cubic foot volume outside bark of trees from diameter (DBH); MAF = multiplicative adjustment factor to eliminate logarithmic bias; N = sample size; F = calculated F statistic with 1 and N-1 degrees of freedom; $p > F$ = probability of exceeding this F value if slope = 0; and adj $Rr^2$ = adjusted $R^2$

| Age | N | MAF | ln(A) | B | F | p>F | adj $R^2$ |
|---|---|---|---|---|---|---|---|
| 12 | 406 | 0.999 | -2.3873 | 2.0230 | 4216.088 | 0.0001 | 0.9121 |
| 15 | 67 | 1.012 | -2.3806 | 2.1348 | 112.021 | 0.0001 | 0.6236 |
| 16 | 94 | 0.950 | -1.7353 | 1.8796 | 140.677 | 0.0001 | 0.5977 |
| 19 | 231 | 0.988 | -2.0203 | 2.0568 | 1462.477 | 0.0001 | 0.8635 |
| 24 | 388 | 0.989 | -2.0459 | 2.1258 | 3830.457 | 0.0001 | 0.9080 |
| 27 | 294 | 0.975 | -2.243 | -2.2068 | 3695.929 | 0.0001 | 0.9263 |

variables on volume growth, accumulated volume (present volume, plus the sum of all previous cuts) was regressed on categorical variables which represented blocking, basal area level, pruning area, and the interaction between thinning and pruning using the general linear models procedure of the SAS statistics package. Additionally, Duncan's multiple range test was used to determine where the significant differences actually occurred.

Data summarization

A number of FORTRAN programs and the SAS statistical package were used to collect and summarize the accumulated data for all six inventories. Whenever an actual tree volume was missing, it was calculated from equation 2. The number of trees, the quadratic mean diameter and its standard deviation, the average total height and its standard deviation, and the average basal area per acre were summarized by density level. Since the previously mentioned ANOVA indicated that volume was affected by both density and pruning levels, both of these variables were used to describe the effect of treatment on total stem volume.

In order to express more properly the effect of density and crown ratio on volume growth, two new variables were calculated: volume weighted basal area and volume weighted crown ratio. Volume weighted basal area is an average basal area calculated as follows:

1 - multiply the initial basal area at age 12 by the cubic-foot volume at that age;

2 - calculate the mean of the basal area left after thinning at one age and the before thinning basal area of the following age;

3 - multiply these mean basal areas by the cubic foot volume which grew during this time span;

4 - sum the weighted basal areas from (1) and (3) above; and

5 - divide by the volume before thinning at the last age.

Volume weighted crown ratio is calculated in a similar manner with crown ratio substituted for basal area. These calculations resulted in average basal areas of 49, 68, 86, and 102 square feet per acre respectively for the treatment levels of 30, 50, 70, and 90 square feet per acre. The volume weighted average live crown ratios were respectively 44, 50, and 51 percent for the treatments 25, 40, and 55 percent with the unpruned plots having an average crown ratio of 55 percent.

Mean annual increment and its culmination

Mean annual increment (MAI) can be used to compare the growth rates of different stands at a given point in time and its maximum or culmination is usually used to determine rotation age. For this analysis, our control plots and the previously mentioned storm-damaged plots were excluded, the control plots because we do not yet have a history of their growth and the damaged plots because they are not representative of their normal treatments.

To find the age at which MAI is maximized the accumulated volumes at each age were calculated. Accumulated volume is the before-cut volume at any given inventory age plus the sum of all previously removed volumes. Using this series of ages and volumes the technique of Clutter and others (1983) was applied. This technique involves the fitting of the following equation to the yield and age data.

$$Y = Ae^{B/t} \tag{3}$$

where:

$Y$ = yield at time $t$; $t$ = age of yield data;
$e$ = the base of the natural logarithm, and
$A$ and $B$ are estimated coefficients.

This technique is especially appealing because of the simplicity of the equation and the fact that the age of culmination for mean annual increment is just $-B$. This equation was fitted using a nonlinear package written by the authors and the age of maximum MAI was determined and used to calculate the expected mean annual increment at this age.

In addition to the calculation of the actual maximum, a sensitivity analysis was done to determine the range of practical cutting ages. This analysis was done by trying different ages in the equations fitted above until a mean annual increment 10 percent less than the maximum was found. This percent was chosen because it was felt that it would encompass the acceptable error in actual forest management practice.

RESULTS AND DISCUSSION

Descriptive stand variables

In order to present a full picture of stand development under different thinning regimes the average number of trees per 0.1 acre plot before and after thinning, quadratic mean diameter and its standard deviation before and after thinning, average total height and its standard deviation before thinning, and the average basal area per acre before and after thinning are presented in Table 2.

Volume

Volume was calculated in terms of merchantable units and for the whole stem. For the purposes of this paper only total stem volume in cubic feet outside bark is presented. Table 3 shows this volume before and after thinning for all inventory ages by both pruning and density levels.

Table 2. Stand variables before (B) and after (A) thinning by density level for all measurement ages. Data basis: 10, 10, 9, 8 and 5 0.1-acre plots for density levels 30, 50, 70, 90 and control plots, respectively. CN = control plots.

| | Age, years | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Density level | 12 | | 15 | | 16 | | 19 | | 24 | | 27 | |
| | B | A | B | A | B | A | B | A | B | A | B | A |
| | Number of plot trees TOT = total number of trees. | | | | | | | | | | | |
| 30 | 225 | 157 | 157 | 67 | 67 | 56 | 56 | 56 | 56 | 28 | 28 | 23 |
| 50 | 290 | 233 | 233 | 123 | 123 | 90 | 90 | 90 | 90 | 49 | 49 | 42 |
| 70 | 346 | 304 | 304 | 183 | 183 | 134 | 134 | 132 | 132 | 78 | 78 | 64 |
| 90 | 364 | 337 | 337 | 223 | 223 | 156 | 156 | 154 | 154 | 105 | 105 | 88 |
| TOT | 1225 | 1031 | 1031 | 596 | 596 | 436 | 436 | 432 | 432 | 260 | 260 | 217 |
| CN | . | . | . | . | . | . | . | . | . | . | 131 | 131 |
| | Quadratic mean diameter in inches | | | | | | | | | | | |
| 30 | 6.6 | 6.8 | 8.6 | 9.0 | 9.6 | 9.8 | 11.8 | 11.8 | 14.0 | 14.1 | 15.8 | 15.8 |
| 50 | 6.8 | 6.9 | 8.2 | 8.7 | 9.1 | 9.3 | 11.0 | 11.0 | 12.8 | 13.4 | 14.8 | 14.8 |
| 70 | 6.5 | 6.6 | 7.6 | 7.9 | 8.3 | 8.5 | 9.9 | 9.9 | 11.3 | 12.0 | 13.2 | 13.2 |
| 90 | 6.5 | 6.5 | 7.3 | 7.7 | 8.0 | 8.2 | 9.4 | 9.4 | 10.6 | 11.1 | 12.1 | 12.1 |
| CN | . | . | . | . | . | . | . | . | . | . | 9.3 | 9.3 |
| | Standard deviation of diameter in inches | | | | | | | | | | | |
| 30 | 1.13 | 0.90 | 1.18 | 1.02 | 1.16 | 1.12 | 1.44 | 1.44 | 1.67 | 1.55 | 1.70 | 1.63 |
| 50 | 1.02 | 1.00 | 1.17 | 1.00 | 1.06 | 0.96 | 1.20 | 1.20 | 1.53 | 1.22 | 1.37 | 1.36 |
| 70 | 1.09 | 1.00 | 1.20 | 1.05 | 1.12 | 1.07 | 1.31 | 1.31 | 1.65 | 1.27 | 1.39 | 1.20 |
| 90 | 1.06 | 1.04 | 1.32 | 1.01 | 1.08 | 1.07 | 1.28 | 1.26 | 1.62 | 1.54 | 1.80 | 1.86 |
| CN | . | . | . | . | . | . | . | . | . | . | 2.59 | 2.59 |
| | Average total height in feet | | | | | | | | | | | |
| 30 | 36.2 | | 43.1 | | 45.3 | | 52.0 | | 62.7 | | 68.2 | |
| 50 | 36.3 | | 43.7 | | 46.3 | | 52.8 | | 65.0 | | 70.9 | |
| 70 | 36.0 | | 42.6 | | 44.1 | | 51.5 | | 63.0 | | 69.4 | |
| 90 | 35.9 | | 41.9 | | 41.6 | | 49.9 | | 60.9 | | 67.9 | |
| CN | . | | . | | . | | . | | . | | 57.1 | |
| | Standard deviation of height in feet | | | | | | | | | | | |
| 30 | 2.7 | | 2.9 | | 3.8 | | 3.4 | | 4.1 | | 4.3 | |
| 50 | 3.2 | | 3.6 | | 5.0 | | 4.3 | | 5.2 | | 5.1 | |
| 70 | 3.1 | | 3.8 | | 5.5 | | 4.3 | | 5.2 | | 4.7 | |
| 90 | 3.6 | | 4.8 | | 5.4 | | 4.1 | | 5.0 | | 6.0 | |
| CN | . | | . | | . | | . | | . | | 10.4 | |
| | Average basal area in square feet per acre | | | | | | | | | | | |
| 30 | . | 40 | 64 | 30 | 34 | 30 | 42 | 42 | 60 | 31 | 38 | 32 |
| 50 | . | 60 | 86 | 50 | 56 | 43 | 60 | 60 | 80 | 48 | 58 | 51 |
| 70 | . | 80 | 106 | 70 | 76 | 58 | 79 | 79 | 103 | 68 | 82 | 69 |
| 90 | . | 97 | 122 | 91 | 98 | 72 | 93 | 93 | 117 | 88 | 104 | 89 |
| CN | . | . | . | . | . | . | . | . | . | . | 123 | 123 |

Table 3. Total stem volume outside bark in cubic feet per acre before (B) and after (A) thinning by density level and pruning level for all measurement ages.
MN = mean for all pruning level;
CN = control (no pruning).

| Pruning level as a pct. of Live crown | Age, years 12 | | 15 | | 16 | | 19 | | 24 | | 27 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | A | B | A | B | A | B | A | B | A | B | A |
| **Density level 30** | | | | | | | | | | | | |
| 25 | . | 677 | 1430 | 717 | 780 | 567 | 863 | 863 | 1427 | 1000 | 1280 | 1067 |
| 40 | . | 700 | 1447 | 693 | 820 | 793 | 1287 | 1287 | 2113 | 1020 | 1367 | 1047 |
| 55 | . | 710 | 1497 | 680 | 820 | 700 | 1203 | 1203 | 1923 | 957 | 1280 | 1140 |
| CN | . | 760 | 1540 | 690 | 850 | 850 | 1510 | 1510 | 2380 | 810 | 1010 | 1010 |
| MN | . | 702 | 1466 | 696 | 811 | 703 | 1157 | 1157 | 1877 | 974 | 1279 | 1077 |
| **Density level 50** | | | | | | | | | | | | |
| 25 | . | 1050 | 1960 | 1203 | 1323 | 830 | 1263 | 1263 | 2023 | 1680 | 2100 | 1853 |
| 40 | . | 1047 | 1987 | 1153 | 1333 | 1010 | 1687 | 1687 | 2757 | 1660 | 2013 | 1777 |
| 55 | . | 1080 | 2027 | 1173 | 1370 | 1207 | 2027 | 2027 | 3220 | 1560 | 1943 | 1697 |
| CN | . | 1070 | 1880 | 1150 | 1350 | 1230 | 1960 | 1960 | 2880 | 1600 | 2030 | 1730 |
| MN | . | 1060 | 1980 | 1174 | 1343 | 1037 | 1689 | 1689 | 2688 | 1630 | 2020 | 1771 |
| **Density level 70** | | | | | | | | | | | | |
| 25 | . | 1395 | 2295 | 1575 | 1775 | 1085 | 1705 | 1560 | 2535 | 2320 | 2840 | 2350 |
| 40 | . | 1393 | 2387 | 1577 | 1787 | 1427 | 2280 | 2280 | 3507 | 2287 | 2733 | 2350 |
| 55 | . | 1427 | 2500 | 1610 | 1883 | 1547 | 2393 | 2393 | 3603 | 2270 | 2740 | 2380 |
| CN | . | 1450 | 2300 | 1520 | 1770 | 1600 | 2490 | 2490 | 3810 | 2330 | 2860 | 2360 |
| MN | . | 1411 | 2394 | 1581 | 1814 | 1410 | 2213 | 2181 | 3357 | 2293 | 2773 | 2361 |
| **Density level 90** | | | | | | | | | | | | |
| 25 | . | 1780 | 2830 | 2070 | 2250 | 1330 | 2000 | 1920 | 3130 | 3130 | 3800 | 3190 |
| 40 | . | 1633 | 2610 | 2050 | 2283 | 1443 | 2157 | 2133 | 3267 | 2657 | 3203 | 2900 |
| 55 | . | 1723 | 2813 | 2047 | 2317 | 1887 | 2917 | 2897 | 4103 | 2867 | 3547 | 2947 |
| CN | . | 1810 | 2780 | 2040 | 2300 | 1960 | 2940 | 2940 | 4080 | 2840 | 3410 | 2990 |
| MN | . | 1707 | 2735 | 2050 | 2294 | 1660 | 2520 | 2494 | 3665 | 2818 | 3432 | 2965 |
| **All density levels** | | | | | | | | | | | | |
| 25 | . | 1083 | 1954 | 1220 | 1346 | 854 | 1310 | 1269 | 2061 | 1757 | 2180 | 1850 |
| 40 | . | 1193 | 2108 | 1368 | 1556 | 1168 | 1852 | 1847 | 2911 | 1906 | 2329 | 2018 |
| 55 | . | 1235 | 2209 | 1378 | 1597 | 1335 | 2135 | 2130 | 3213 | 1913 | 2378 | 2041 |
| CN | . | 1273 | 2125 | 1350 | 1567 | 1410 | 2225 | 2225 | 3287 | 1895 | 2328 | 2023 |

In addition to the volume present at each inventory, the accumulated volume per acre produced by each treatment was also calculated. This information is presented in Table 4.

The most obvious trend in Table 4 is that volume increases with both basal area and percent of live crown. This can best be shown by figures 1 and 2. Figure 1 shows the actual accumulated volume present on each study plot as function of its actual basal area and average crown ratio. Figure 2 is the same data which has been smoothed by the following simple regression function:

$$VOL=a +b(BA) +c(BA^2) +d(CR) +e(CR^2) +f(BACR) \quad (3)$$

Table 4. Total accumulated stem volume at age 27 in cubic feet per acre. This is the volume at age 27 plus all previously removed volume.

| Pruning level as a pct of live crown | Density level 49 | 68 | 86 | 102 | all (83) |
|---|---|---|---|---|---|
| 44 | 3851 | 4538 | 5110 | 5675 | 4563 |
| 50 | 4436 | 5115 | 5625 | 5499 | 5169 |
| 51 | 4368 | 5435 | 5767 | 6171 | 5436 |
| 55 | 4565 | 4985 | 5735 | 5815 | 5274 |
| all (49) | 4253 | 5025 | 5570 | 5812 | 5119 |

where:
VOL = the accumulated total cubic foot volume outside bark; a through f are estimated coefficients; BA = volume weighted average basal area; CR = the volume weighted average crown ratio; and BACR = BA x CR.

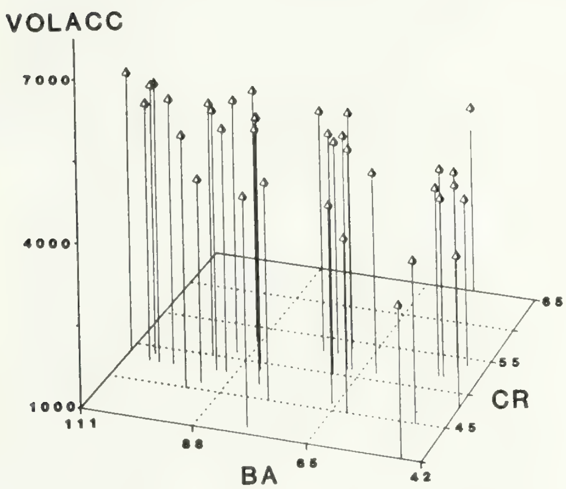


Figure 1. Total accumulated volume at Age 27 as a function of basal area and crown ratio. BA = basal area in square feet per acre; CR = length of live crown divided by total tree height; and VOLACC = cubic-foot volume outside bark at age 27 plus all previously removed volume.

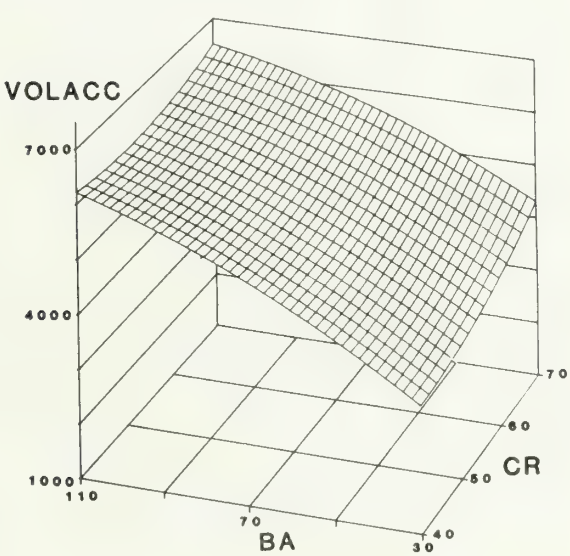


Figure 2. Total accumulated volume at Age 27 as a function of basal area and crown ratio. BA = basal area in square feet per acre; CR = length of live crown divided by total tree height; and VOLACC = cubic-foot volume outside bark at age 27 plus all previously removed volume.

Analysis of variance

When an analysis of variance was calculated for the total outside bark cubic foot volume, it was shown that the density level and the pruning level were highly significant. These relationships were significant regardless of whether or not the control plots were included in the analysis. The block and the interaction between pruning and density level were nonsignificant. It is interesting to note that the previous progress report (Burton 1976) did not show pruning level to be a significant factor in volume yield.

In order to examine more thoroughly the effects of pruning on the volume yield of loblolly pine, as mentioned above, a Duncan's multiple range test was used. This test revealed that the accumulated cubic foot volume increased significantly with the increase in crown ratio among the pruning treatments tried. The unpruned plots had a lower volume than that of trees pruned to a 55 percent live crown ratio (actual average if 51 percent), but this difference was not significant.

In addition to a standard analysis of variance in which pruning, thinning, blocking, and the interaction between thinning and pruning were treated as qualitative variables a regression analysis was done on the effect of thinning and pruning. The model employed to produce Figure 2 was too collinear to trust for significance tests so a more simple model was used. In this model, shown below, volume weighted basal area and crown ratio were used as continuous independent variables and accumulated volume at age 27 was the dependent variable.

$$VOL = a + b(BA) = c(CR) \qquad (4)$$

where:
VOL = the accumulated total cubic foot volume outside bark; a through c are estimated coefficients; BA = volume weighted average basal area; and CR = the volume weighted average crown ratio.

The results of this regression ANOVA were that basal area level is significant but pruning level is not.

Culmination of mean annual increment

The average age at which mean annual increment for cubic foot volume growth peaks is 25 years. At this age the mean annual increment is about 216 cubic feet per acre per year. The ages and their respective mean annual increments for each density and pruning treatment are shown in tables 5 and 6 respectively. To get a better feel for how the density and crown ratio affect mean annual increment this data is also presented graphically in figures 3 and 4.

Table 5. Age of maximum MAI of total stem volume.

| Pruning level as a pct of live crown | Density level | | | | |
|---|---|---|---|---|---|
| | 49 | 68 | 86 | 102 | all (83) |
| 44 | 14 | 18 | 21 | 23 | 18 |
| 50 | 18 | 21 | 23 | 23 | 21 |
| 51 | 17 | 23 | 23 | 25 | 22 |
| 55 | 19 | 21 | 25 | 24 | 22 |
| all (49) | 17 | 21 | 23 | 24 | 22 |

Table 6. Maximum MAI of total stem volume in cubic feet per acre. MAI's correspond to the ages shown in table 5.

| Pruning level as a pct of live crown | Density level | | | | |
|---|---|---|---|---|---|
| | 49 | 68 | 86 | 102 | all (83) |
| 44 | 168 | 181 | 194 | 210 | 180 |
| 50 | 175 | 197 | 213 | 207 | 197 |
| 51 | 176 | 207 | 218 | 230 | 206 |
| 55 | 182 | 191 | 214 | 218 | 200 |
| all (49) | 173 | 194 | 210 | 217 | 216 |

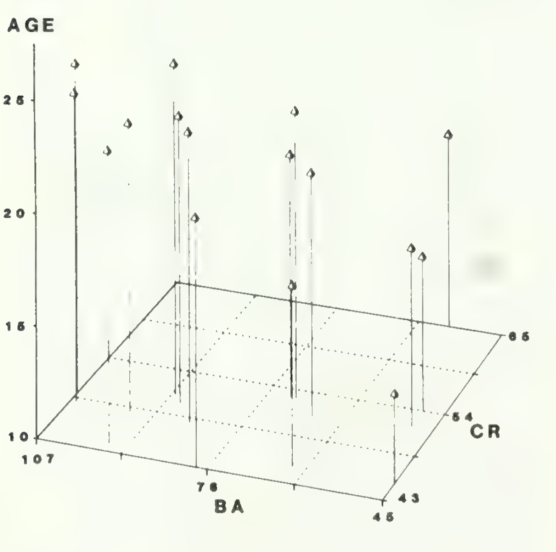


Figure 3. Age of maximum mean annual volume increment as a function of basal area and crown ratio.
BA = basal area in square feet per acre; and
CR = length of live crown divided by total tree height.

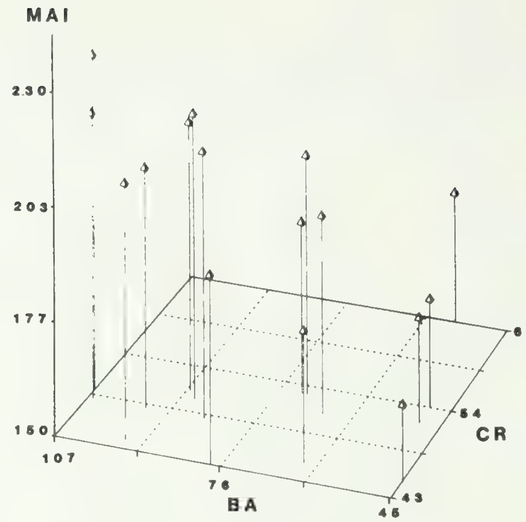


Figure 4. Maximum annual increment as a function of basal area and crown ratio.
BA = basal area in square feet per acre; and
CR = length of live crown divided by total tree height.

In addition to the straightforward answers obtained for the age and volume of stands with maximum mean annual increment, a sensitivity analysis was conducted. For each density level the age was found when mean annual increment was 10 percent less than the maximum. These results are presented in Table 7.

Table 7. Sensitivity analysis of the total stem volume at rotation age for all density levels.

| Age of | Density level | | | | |
|---|---|---|---|---|---|
| | 49 | 68 | 86 | 102 | all (83) |
| 0.9 MAX (MAI) | 11 | 13 | 15 | 16 | 15 |
| MAX (MAI) | 17 | 21 | 23 | 24 | 22 |
| 0.9 MAX (MAI) | 28 | 34 | 38 | 39 | 36 |

SUMMARY AND CONCLUSIONS

This study of the effects of thinning and pruning on the growth of planted loblolly pine is not yet complete but already some valuable results have been obtained. As would be expected, diameter growth (and thus basal area growth) is fastest on heavily thinned plots. The current average diameter of the plots thinned to 30 square feet of basal area per acre is 70 percent better than the control plots. Neither height growth nor wood density seems to have been affected by the experimental treatment.

Total cubic foot volume yield increases with both density and crown ratio. The highest yield is 60 percent greater than the lowest.

Averaged over all treatments, mean annual increment culminates at age 22 with an average volume growth of 216 cubic feet per acre per year. This age ranges between 14 and 25 years and the MAI ranges between 168 and 230 cubic feet.

The existence of a gradient in total volume produced which was related to the density of the stand does not agree with the conclusion of Wiedemann (1932) and others that within a wide range of density, productivity is independent of thinning intensity. It shows that there is some biological reason to continue the search for the best density level aside from finding the best distribution of volume from smaller to larger stems. This study reveals the direction in which the answer lies, but not the actual optimum for loblolly pine, since our maximum occurs at the limits of the study treatments.

It is known that the removal of lower, shaded branches which consume more photosysnthate than they produce increases volume yield (Smith 1962). This effect is readily observed in our study. At all density levels, except the lowest, volume growth is greater when the trees were lightly pruned rather than left unpruned. This exception strengthens rather than contradicts the rule because in the most heavily thinned plots where the lower branches were not shaded. growth was increased by the presence of these branches. This effect, though present, is slight and does not show up in our attempts at modeling.

This paper only examined some basic stand description variables and the total cubic foot volume growth outside bark. There is much more which could be extracted from the collected data including an analysis of merchantable volume, but that will be more meaningful after the MAI culminates in a few years. Additionally, there are other factors like the effect of ice damage on volume growth, and the effects of thinning on crown form which remain to be investigated.

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# Growth and Yield

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# Estimating the Amount of Wood Per Acre in Loblolly and Slash Pine Plantations in East Texas[1]

J. David Lenhart[2]

Abstract.--Two diameter distribution yield prediction systems are presented for loblolly pine (Pinus taeda L.) and slash pine (Pinus elliotti Engelm.) plantations located on non-old-fields in East Texas. A separate system was developed for each species based on the initial measurement of the East Texas Pine Plantation Research Project permanent plots.

Loblolly and slash pine plantations established on sites converted from mixed pine-hardwood stands in East Texas are approaching possible utilization. In order to optimize the utilization of these plantations, estimation of the amount of wood per acre is needed. If the per acre yields can be described on a diameter class basis, it would assist the forest manager in assigning different stumpage prices to various tree size classes.

This paper presents a method to predict the stand structure--number of trees per acre by diameter classes and individual total tree heights by dbh classes--and, subsequently, the amount of wood per acre by diameter classes for loblolly and slash pine plantations in East Texas.

## PERMANENT PLOT MEASUREMENTS

The East Texas Pine Plantation Research Project (ETPPRP) permanent plots were installed and measured during the summers of 1982, 1983 and 1984. A total of 174 plots were established in loblolly pine plantations and 78 in slash pine plantations. Each permanent plot consists of two subplots--one to remain unthinned, and the other will eventually receive thinning treatments (Lenhart et al. 1985). The diameter distribution yield prediction systems were developed using data from the subplots-to-remain-unthinned (regression subplots), and the systems were evaluated using the subplots-to-be-thinned (evaluation subplots).

Observed values available for stand structure analysis were:

1. Age-number of growing seasons completed-(A).
2. Stand height-average height of the ten tallest trees-(H).
3. Total number of trees per acre by dbh class-(T).
4. Number of trees per acre by diameter class.
5. Minimum diameter-(DMIN).
6. Arithmetic mean diameter-(DMEAN).
7. Quadratic mean diameter-(DQMEAN).
8. Maximum diameter-(DMAX).

A site index (base age=25 years) value (S) was predicted for each plot using appropriate equations developed by Blackard (1985a, 1986) and Lenhart et al. (1986).

An exploratory analysis of fitting the Weibull distribution to the observed number of trees per acre by diameter class indicated that a regression subplot had to have trees in three dbh classes or more. If two dbh classes or less were occupied, the fitting routines would usually fail to find a solution. As a result, the number of loblolly pine plots available for analysis was reduced from 174 to 77, and the slash pine plots were reduced from 78 to 43.

For the 77 loblolly pine regression subplots, average stand parameters are:

1. Age=9 years.
2. Height of the ten tallest trees=31 feet.
3. Site index=72 feet.
4. Number of trees per acre=457.
5. Minimum diameter=1.2 inches.
6. Arithmetic mean diameter=4.2 inches.
7. Quadratic mean diameter=4.4 inches.

[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia.

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For the 43 slash pine regression subplots, average stand parameters are:

1. Age=8 years.
2. Height of the ten tallest trees=27 feet.
3. Site index=67 feet.
4. Number of trees per acre=457.
5. Minimum diameter=1.2 inches.
6. Arithmetic mean diameter=4.2 inches.
7. Quadratic mean diameter=4.4 inches.

## PREDICTING STAND STRUCTURE AND YIELD

A Weibull parameter recovery procedure developed by Burk and Burkhart (1984) was selected to fit the Weibull distribution to the regression subplots. Diameter distribution yield prediction systems for each species are described as:

### Loblolly

1. Determine:

   a. Number of growing seasons completed since plantation establishment (A).

   b. Number of surviving trees per acre (T) at that age.

   c. Average total height of ten tallest trees (H) in plantation. If unknown, but site index (S)(base age=25 years) is known, then predict H using:

   $$H=S((1-\exp(-0.08005275A))/0.8648429)^{1.628569}$$

   (This equation was developed by Blackard 1985a, 1986 and Lenhart et al. 1986.)

2. Predict:

   a. Dbh of smallest tree (DMIN) in plantation, using:

   $$DMIN=-0.08975+0.05913H-0.00126498T$$

   $$(R^2=67\%)$$

   If DMIN is less than 0, DMIN=0.

   b. Quadratic mean dbh (DQMEAN) for plantation, using:

   $$DQMEAN=10^{(1.17470-12.93480(1/H)-0.000196042T)}$$

   $$(R^2=96\%)$$

   c. Arithmetic mean dbh (DMEAN) for plantation, using:

   $$DMEAN=-0.13343=0.99393DQMEAN$$

   $$(r^2=99\%)$$

3. Compute the expected number of trees per acre for the plantation using the Weibull distribution. Weibull parameters are "recovered" with techniques developing by Burk and Burkhart (1984). The recovery process is:

   a. Location parameter (a) is equal to DMIN.

   b. Shape parameter (c) is calculated by solving the following equation:

   $$(DQMEAN)^2-a^2-2a(DMEAN-a)$$
   $$-(DMEAN-a)^2\,\Gamma(1+2/c)/\,\Gamma(1+1/c)=0$$

   where: $\Gamma$ =The complete gamma function.

   c. Scale parameter (b) is obtained using:

   $$b=(DMEAN-a)/\,\Gamma(1+1/c)$$

   Solve the Weibull distribution to determine the proportion (P) of T in each dbh class as:

   $$d_1<P<d_u=\exp(-((d_1-a)/b)^c)-\exp(-((d_u-a)/b)^c)$$

   where: $d_1$, & $d_u$=lower & upper bound of diameter class.

   Multiply each P by T to obtain the expected number of trees per acre (n) in each dbh class.

4. Predict the total height (h) of each tree with dbh class mid-point dbh (d) (5.0, 6.0, etc.) using:

   $$h=\exp(\ln(H)+0.0071609-0.125051\ln(A)(\ln(DMAX)-\ln(d))$$
   $$-0.133671\ln(H/A)(\ln(DMAX)-\ln(d))$$
   $$+0.004339\ln(T)(\ln(DMAX)-\ln(d))$$

   $$(R^2=68\%)$$

   Where: DMAX=Dbh of largest tree in plantation.

   (This equation developed by Blackard 1985b, 1986.)

5. Estimate the content (cubic feet, green weight, etc.) of the tree representing each dbh class mid-point.

   An equation to estimate the cubic feet of wood (CFW) in a planted loblolly pine tree in East Texas is:

   $$CFW=0.000928d^{1.973735}h^{1.213909}$$

   $$(R^2=99\%)$$

   (This equation developed by Wiswell et al. 1986.)

6. For the loblolly pine plantation, we now know:

   a. The number of trees per acre (n) for each dbh class.

b. The cubic feet of wood per tree (CFW) for each dbh class.

Multiply CFW by n to obtain the cubic feet of wood per acre by dbh class.
Sum the CFW values across all dbh classes to determine the total cubic feet of wood per acre.

By selective summing across specified dbh classes, the CFW per acre by various tree size groups or different products (pulp, chip-n-saw, lumber, plywood, etc.) can be calculated.

Slash

1. Determine:

   a. Number of growing seasons completed since plantation establishment.

   b. Number of surviving trees per acre at that age.

   c. Average total height of ten tallest trees in plantation. If unknown, but site index (base age=25 years) is known, then predict H using:

$$H=S((1-\exp(-0.07488801A))/0.846215)^{1.4502401}$$

(This equation was developed by Blackard 1986, 1985a and Lenhart et al. 1986.)

2. Predict:

   a. Dbh of smallest tree in plantation, using:

$$DMIN=-0.22481+0.06496H-0.00126741T$$

$$(R^2 66\%)$$

If DMIN is less than 0, DMIN=0.

   b. Quadratic mean dbh for plantation, using:

$$DQMEAN=10^{(1.09600-11.70271(1/H)-0.000162166T)}$$

$$(R^2=96\%)$$

   c. Arithmetic mean dbh for plantation, using:

$$DMEAN=-0.12272+0.99560DQMEAN$$

$$(r^2=99\%)$$

3. Compute the expected number of trees per acre for the plantation using the Weibull distribution. Weibull parameters are "recovered" with technique developed by Burk and Burkhart (1984). The recovery process is:

   a. Location parameter is equal to DMIN.

   b. Shape parameter is calculated by solving the following equation:

$$(DQMEAN)^2-a^2-2a(DMEAN-a)$$
$$-(DMEAN-a)^2\Gamma(1+2/c)/\Gamma(1+1/c)=0$$

   c. Scale parameter is obtained using:

$$b=(DMEAN-1)/\Gamma(1+1/c)$$

Solve the Weibull distribution to determine the proportion of T in each dbh class as:

$$d_l<P<d_u=\exp(-((d_l-a)/b)^c)-\exp(-((d_u-a)/b^c)$$

Computer software can be easily developed to solve Eq. 7.

Multiply each P by T to obtain the expected number of trees per acre in each dbh class.

4. Predict the total height (h) of each tree with dbh class mid-point dbh (d)(5.0, 6.0, etc.) using:

$$H-\exp(\ln(H)+0.0045959-0.166041\ln(A)(\ln(DMAX)$$
$$-\ln(d)$$
$$-0.151721\ln(H/A)(\ln(DMAX)-\ln(d)$$

$$(R^2=69\%)$$

(This equation developed by Blackard 1985a, 1986.)

5. Estimate the content (cubic feet, green weight, etc.) of the tree representing each dbh class mid-point.

An equation to estimate the cubic feet of wood in a planted slash pine tree in East Texas is:

$$CFW=0.000838d^{1.859736}h^{1.301908}$$

$$(R^2=99\%)$$

(This equation developed by Hackett 1986.)

6. For the slash pine plantation, we now know:

   a. The number of trees per acre for each dbh class.

   b. The cubic feet of wood per tree for each dbh class.

Multiply CFW by n to obtain the cubic feet of wood per acre by dbh class.

Sum the CFW values across all dbh classes to determine the total cubic feet of wood per acre.

By selective summing across specified dbh classes, the CFW per acre by various tree size groups or different products (pulp, chip-n-saw, lumber, plywood, etc.) can be calculated.

## EVALUATION

### Loblolly

Using evaluation subplot values, plottings of the differences between observed yields and predicted yields against various stand parameters indicated no adverse trends. On the average, an under-prediction of 44 cubic feet or 7 percent occurred.

### Slash

Based on the evaluation subplot values, plottings of the differences between observed yields and predicted yields against various parameters indicated no adverse trends. On the average, an under-prediction 37 cubic feet or 11 percent occurred.

## ACKNOWLEDGMENT

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# UPDATE OF LONG TERM LOBLOLLY PINE PLANTATION GROWTH AND YIELD STUDY ON THE CLEMSON EXPERIMENTAL FOREST[1]

L. E. Nix, A. T. Shearin, and S. K. Cox[2]

ABSTRACT.--Clemson University's long term loblolly pine plantation growth and yield study provides the results of 47 years of growth of plantations established on old fields in the upper Piedmont of South Carolina. Diameter growth has peaked in these plantations and is apparently decreasing. The reduction in growth rate is not wholly explained by the age of the stands or any changes in the thinning regime. Unthinned plots average 9.3 inches dbh while thinned plots average 11.5 inches dbh. Diameter growth on several of the most heavily thinned plots has failed to show the response expected relative to the site index. Analysis of the Girard Form Class of thinned versus unthinned plots indicates that differences found at age 42 are disappearing. Unthinned plots average 79 in FC while thinned plots average 80 in FC. A preliminary analysis of the relation between form class and diameter class for the sample of trees measured on all plots indicates a curvilinear relationship with trees at either end of the diameter class range having lower form class values than trees near the median diameter class. Average form class values range from a low of 78 on the poorest plot to a high of 82 on the best plot. Thinning effects may primarily be caused by removal of small diameter trees which have lower form class values than median diameter trees. Six inch dbh trees average 72 FC, 12 inch dbh trees average 81 FC, and 18 inch dbh trees average 78 FC.

## INTRODUCTION

Clemson University's Department of Forestry has maintained a long-term thinning study for the past 33 years in old-field Piedmont loblolly pine (*Pinus taeda* L.) plantations on the Clemson Experimental Forest in upper South Carolina (Shearin et al. 1985). The stands are now 47 years old and have been thinned 5-6 times during the study starting at about age 15 years. Low thinnings have been used to maintain residual basal area stocking guidelines for treatment plots ranging from 75 $ft^2$ to 135 $ft^2$ basal area per acre. The stands were planted on abandoned agricultural lands by the Works Progress Administration in the late 1930's at 6 x 6, 6 x 7, and 6 x 8 feet spacing with Coastal Plain loblolly stock. Thirty-two study plots ranging in size from 0.1 to 0.6 acres with half chain buffers were established around 1953 on sites ranging from site index base age 50 years ($SI_{50}$) 76 to 103 on Cecil-Madison sandy clay loam soils in various stages of erosion. Twenty-two of the original plots remain intact, with fifteen of these grouped (3-4) at each location, usually including a range of basal areas and an unthinned control plot. Stand data have been reported for 15 plots which have been actively maintained and have an unthinned control plot adjacent (Shearin et al. 1985). Thinnings have been conducted at 5-8 year intervals or when plot basal area exceeded the specified residual guideline by 25 $ft^2$. Growth has slowed recently and many of the plots have not been thinned in the past eight years.

In the process of monitoring growth and yield on the study plots, Girard form class of sawtimber-size trees was measured to facilitate using the form class volume tables of Mesavage and Girard (1946) to compute sawtimber volumes. Incidental comparison of form class among treatments indicated that trees on thinned plots had higher form class values than those on unthinned plots and that this difference in form at age 42 contributed as much as 8 percent of the sawtimber volume difference between thinned and unthinned plots (Shearin et al. 1985). The current report provides an update of the growth and yield values and a further analysis of the differences in tree form induced by thinning that were reported at age 42.

## METHODS

Diameter at breast height (dbh) of all trees on each plot was measured (±0.1 inch) with a steel diameter tape and merchantable height of all sawtimber-size trees (dbh >9.5 inches) was ocularly estimated to the nearest half log (16 foot logs) with the aid of a 16 foot pole. Girard form class, total height, and height to a 6 inch diameter outside bark (dob) of at least 20 percent of the trees in each one inch diameter class on each plot were determined with the aid of a tree ladder, a clinometer, and an optical dendrometer, respectively. Sawtimber volumes in International 1/4 inch rule were calculated for each tree with a computer program using an equation and 3 percent form class correction

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factor derived from the Mesavage and Girard (1946) form class volume tables by Wiant and Castaneda (1977). Pulpwood volumes were calculated using the equation of Schumacher and Coile (1960). Predictive equations for form class were derived using the Statistical Analysis System General Linear Models Procedure (SAS, 1985) with dbh, relative dbh (tree dbh ÷ plot mean dbh), plot basal area and site index as independent variables. Tree taper equations and curves were derived similarly using tree dbh, dob at 17.3 feet (height of upper diameter measurement for Girard form class), height to a 6 inch dob and total height measurements with the SAS General Linear Models Procedure and a quadratic equation form assumed to be parabolic in nature. The tree taper equations were used to predict tree merchantable height to an upper dob equal to 60 percent of dbh as prescribed by Mesavage and Girard (1946) in using their form class volume tables for trees up to 30 inches dbh. The tree taper curves were used for graphical comparison of overall tree taper among diameter classes, thinning intensities, and different site qualities. Taper equation predicted merchantable heights (heights to a dob = 60 percent dbh) were compared to ocularly estimated merchantable heights using the paired Student's t-Test to determine if, in fact, the ocular estimates of merchantable heights conformed reasonably to the specifications of the Mesavage-Girard form class volume tables for merchantable stem volume determinations.

Because there remains little true replication of thinning levels across the range of site qualities in the intact plots of the study, the plots were grouped according to whether they were low, medium, or high basal area residual stocking level and similarly for site index in order to provide replication in statistical comparisons of treatment mean values.

## RESULTS AND DISCUSSION

Volumes per acre and individual tree parameters at age 47 can be compared among the four broad levels of stocking treatment in Table 1. Highest mean sawtimber volumes in this study were produced with the medium residual basal area stocking levels (90-100 $ft^2$/ac). However, caution should be exercised in extrapolating these results to other sites and stands since, due to lack of replication, the higher stocked, thinned plots (110-135 $ft^2$/ac) are all on medium to low quality sites. In particular, the mean tree volume of the higher basal area plots is lower than that of the unthinned controls (Table 1). This incongruity in mean tree volume may be in part due to ocularly overestimating merchantable heights on larger diameter trees and underestimating it on small diameter trees as the estimator invariably tended to take merchantability to the base of the live crown on larger trees, rather than to a fixed upper log dob. The comparison of ocularly estimated merchantable heights with those predicted from tree taper equations using the Mesavage and Girard 60 percent dbh rule showed that ocular estimates significantly differ from taper equation estimates at the .05 level of probability. The ocular method overestimated merchantable heights by from 3 to 14 feet for the 11 to 17 inch dbh classes, respectively; but the 10 inch dbh class was consistently underestimated by an average of 6.4 feet or nearly half of a 16 foot log. The higher basal area plots average 10.2 inches dbh, and thus, tree merchantable heights and volumes may have been underestimated.

There is no statistically significant difference in mean Girard form class values among the treatments for sawtimber size (dbh >9.5 inches) trees (Table 1), although the mean form class for all thinned plots is greater than that for the unthinned plots (Table 2). Mean dbh of thinned plots is less than an inch greater than that of unthinned plots when only trees >9.5 inches dbh are compared, but mean dbh of all trees is more than 2 inches greater on thinned than on unthinned plots (Table 2). Although mean sawtimber volume of thinned plots is nearly 2,000 board feet per acre (BF/ac) more than that of unthinned plots (Table 2), one of the unthinned plots currently has over 20,000 BF/ac; but it is on one the best sites of the study ($SI_{50}$ = 96) and has a mean dbh of only 9.9 inches. One of the thinned plots has only 13,000 BF/ac and averages only 10.3 inches dbh, yet was thinned repeatedly to 85 $ft^2$ basal area per acre residual and was located on a medium site ($SI_{50}$ = 89). This incongruity in diameter growth, volume production and site index remains to be investigated further.

Table 1.--Volume and Girard Form Class of Old Field Plantation Loblolly Pine at Age 47 as Influenced by Thinning in the South Carolina Piedmont.

| Residual Basal Area (sq ft/ac) | Mean Girard Form Class | Mean Tree Volume (BF-Int ¼) | Mean Volume per Acre[a] (BF-Int ¼) | Thinning Yields[b] (cords/ac) |
|---|---|---|---|---|
| 75-85 | 79.7 | 155 | 16,745 | 24.4 |
| 90-100 | 79.7 | 153 | 19,549 | 25.2 |
| 110-135 | 81.0 | 109 | 16,905 | 21.5 |
| 150-200 | 79.4 | 116 | 16,172 | 0 |

[a] Volumes are for trees >9.5" dbh at age 47 years

[b] Unthinned plots averaged 21 cords per acre of residual trees (4.5" < dbh < 9.6") while thinned plots averaged 3.5 cords per acre

Table 2.--Mean Volume and Stand Attributes for Thinned and Unthinned Old Field Plantation Loblolly Pines at Age 47 in the South Carolina Piedmont.

| Sawtimber Volume (BF-Int ¼) | Mean DBH[a] (inches) | Mean Girard Form Class | Mean Basal Area (sq ft/ac) | Mean Tree Volume (BF-Int ¼) |
|---|---|---|---|---|
| THINNED | | | | |
| 17,899 | 12.2 (11.5) | 80.1 | 95 | 145.5 |
| UNTHINNED | | | | |
| 16,172 | 11.5 (9.3) | 79.4 | 175 | 116.0 |

[a] Trees >9.5 inches (mean for all trees in parenthesis)

At age 42, thinned plots averaged nearly 3 Girard form class units higher than did unthinned plots (Shearin et al. 1985); but at age 47 the difference has diminished to less than 1 Girard form class unit and accounts for only about 2 percent of the volume difference between thinned and unthinned plots. However, it can still be concluded that low thinning does not reduce mean form class and may actually improve it by removing smaller diameter trees that have lower form class. This conclusion is supported by Figures 1 and 2 that show the relationship of form class to dbh and relative dbh as a hyperbolic function. The smallest and largest diameter trees have the lowest mean form class and median diameter trees have the highest mean form class. Although the predictive ability of the equations illustrated in Figures 1 and 2 is inconsequential for individual trees ($r^2 = 0.154$ and 0.166, respectively) the narrow 95 percent confidence limits indicate that the predicted mean form class for each diameter class is reasonably valid. The equations derived for both Figures 1 and 2 are statistically significant at the .05 level, but do not necessarily represent a strong, definitive relationship because of the very low coefficient of determination ($r^2$), i.e., predictive functions other than that of an hyperbola may describe equally well the relationship between form class and dbh and relative dbh. However, using the SAS General Linear Models Procedure and a quadratic equation form gave the highest $r^2$ values of the several equation forms that were tried. Based on the predictive functions of Figures 1 and 2, mean form class values of 6 inch dbh trees equals 72, that of 12 inch dbh trees equals 81, and that of 18 inch dbh trees equals 78. Although not really indicating great differences in form class for sawtimber sized trees (dbh >9.5 inches), Figures 1 and 2 demonstrate a range in mean form class values of 78 to 81 for trees of sawtimber size in the study (10 to 19 inches dbh).

Figures 3, 4, and 5 illustrate the taper or form of trees in the range of diameter classes found on the study plots as they were grouped in high, medium, and low site index groups, respectively. The effect of site index, of course, is to alter tree height for a given diameter class, i.e., the better the site, the taller the tree and, thus, the better the form because of less overall average taper. However, close examination of Figures 3-5 indicates that degree of curvature of the tree taper curves may be a good indicator of form, i.e., the greater the curvature, the better form the tree has for a given diameter and total height combination. The least desirable tree taper is a straight line (no curvature) which represents a conical tree form and the least amount of tree volume for a given diameter and total height combination. The taper curves of the trees in the smallest and largest diameter classes have the least amount of curvature, indicating the poorest form, while the curves of trees of the median diameter classes have the greatest curvature, indicating the best overall tree form. Since Figures 1 and 2 indicate a hyperbolic relationship of diameter class and form based on Girard Form Class measurements, it is significant that overall tree form also seems to follow a similar functional relationship with diameter class. This indicates that the quality of overall tree form may be well-described by Girard Form Class.

The effects of diameter class and site quality on overall tree taper or form is illustrated in Figures 6, 7, and 8 which depict the taper curves of trees of the 9, 13, and 16 inch diameter classes, respectively, as they are affected by the site index differences in the plot groups. Differences in site index do not vary greatly among groups (76 to 96), but appear to significantly affect tree form. It appears from the degree of curvature of the taper curves that the median diameter class (13 inch dbh class) has the best form except in the high site group, where the 16 inch dbh class may have equally as good form. However, 16 inch dbh trees may not be in the largest diameter class in the high site group as there were some 17, 18, and 19 inch dbh trees on plots in this site group. In the 13 inch dbh class (Figure 7), the effect of site quality appears to be complex in that the low site group tree taper curve has the greatest curvature, indicating the best form for that diameter/height combination. However, the high site group has the tallest 13 inch dbh trees and, therefore, the best (meaning the least) overall average taper for that diameter class. Interpretation of the effects of site quality on tree form is, thus, confounded by the combined effects of site quality on tree height and on the diameter growth response at a given stocking density. The average tree diameter

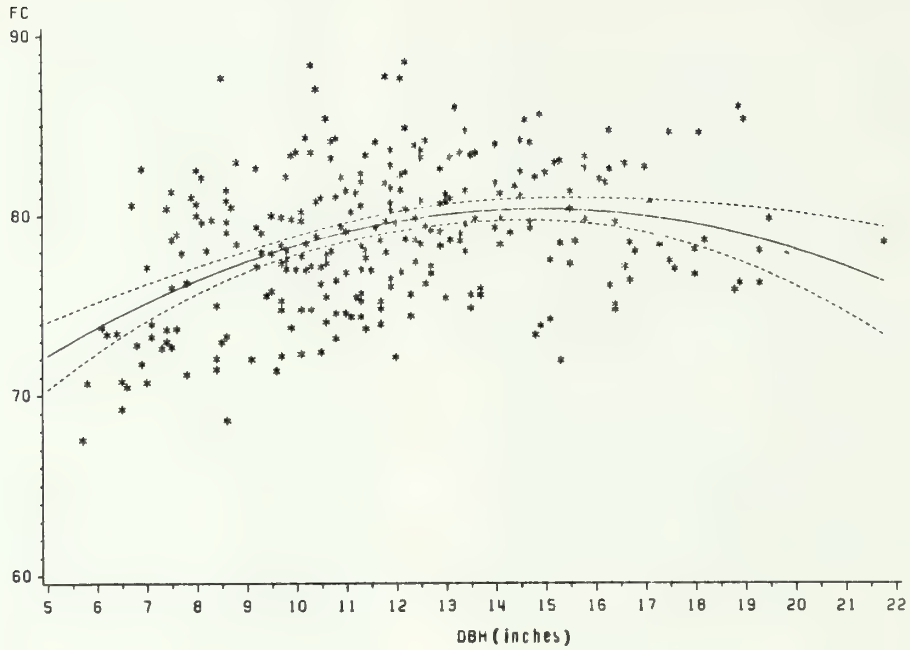


**Figure 1.--Relation of Girard form class to tree dbh with predicted form class for Clemson thinning study (278 trees).**

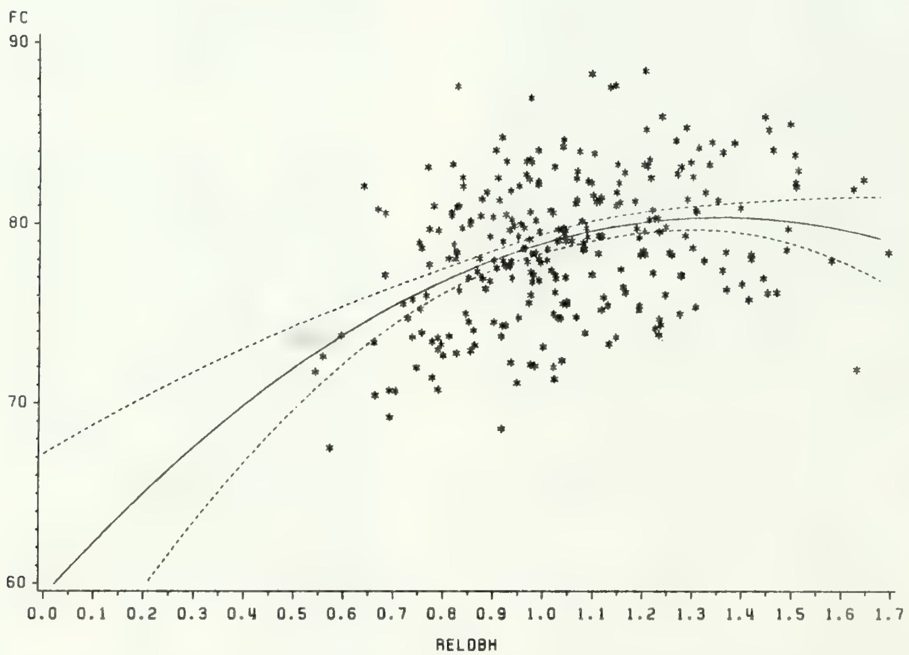


**Figure 2.--Relation of Girard form class to relative tree dbh with predicted form class for Clemson thinning study (278 trees). (Relative dbh = tree dbh/plot mean dbh).**

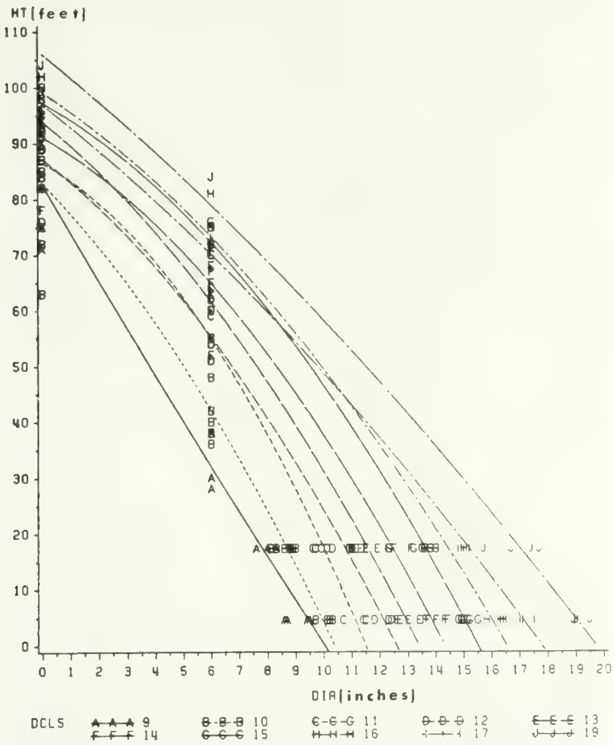


Figure 3.--Tree taper derived from four diameters and heights of loblolly pines in the high site group of the Clemson study.

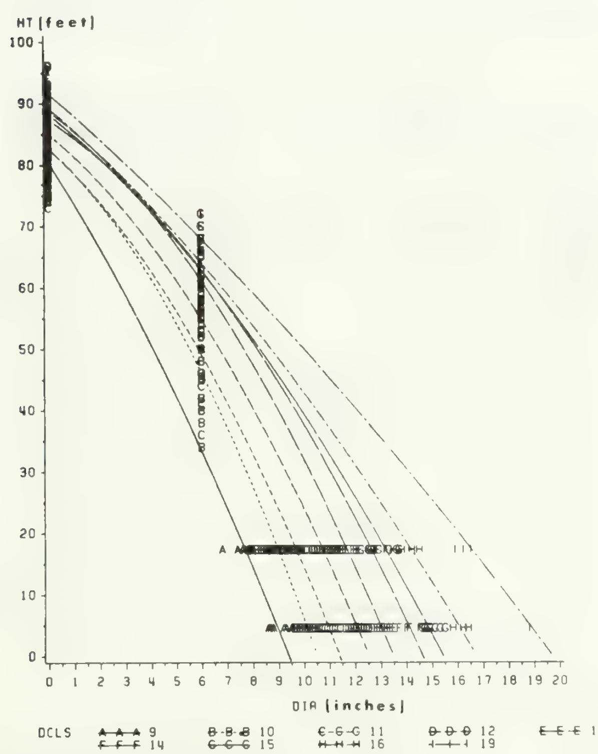


Figure 4.--Tree taper derived from four diameters and heights of loblolly pines in the medium site group of the Clemson study.

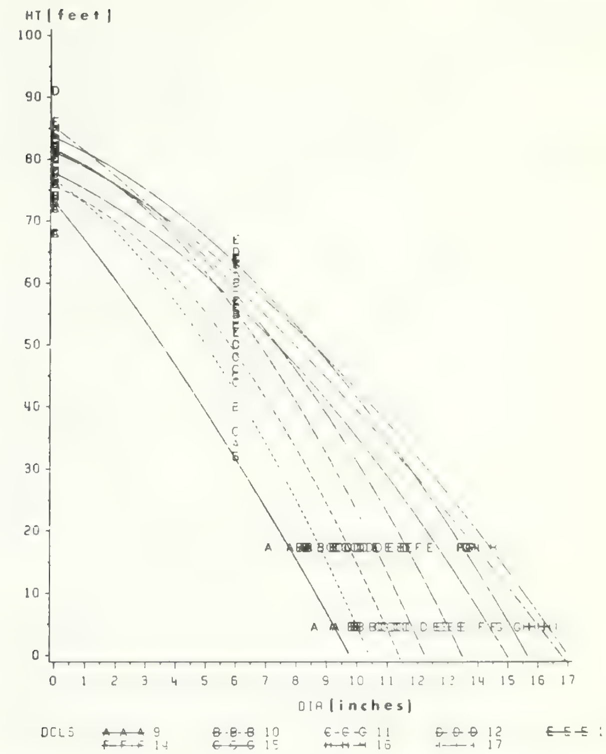


Figure 5.--Tree taper derived from four diameters and heights of loblolly pines in the low site group of the Clemson study.

is greater on a better site at a given stocking level than on a poorer site. Thus, for the sake of comparing tree taper and differing site quality, it might be better to compare the taper of trees according to relative diameter class rather than actual diameter class as has been done in Figures 6-8.

If degree of curvature of a generalized tree taper curve is an indication of tree form quality then, in general, the best form for a given diameter/height combination may occur on poor sites as indicated in Figure 5, the low site group, where all but the trees in the smallest diameter class seem to have taper curves with more curvature (better form) than do trees of the same diameter classes in the medium and high site groups of the study. Caution must again be suggested here as the taper curves developed for the trees in this study were assumed to be of the same form (quadratic) along the entire tree and across all sites and treatment combinations and were based in part on rather crude measurements of upper stem diameters. All that is intended here is to suggest that tree form may be a very complex phenomenon and that assumptions regarding the effects of thinning, site quality, and diameter class on tree taper should be carefully considered.

It is generally assumed that because thinning increases the rate of diameter growth of residual trees and, thus, increases mean diameter in

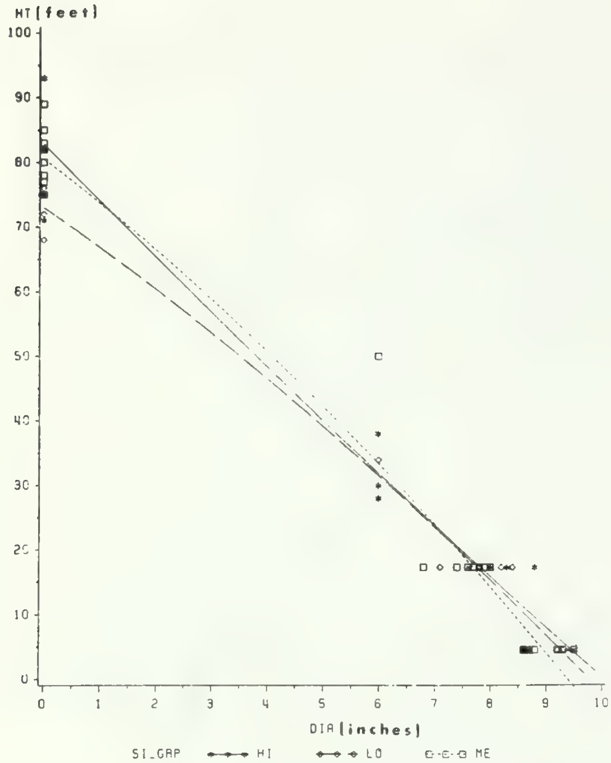


Figure 6.--Tree taper derived from four diameters and heights of 9 inch dbh loblolly pines in high, medium and low site groups of the Clemson study.

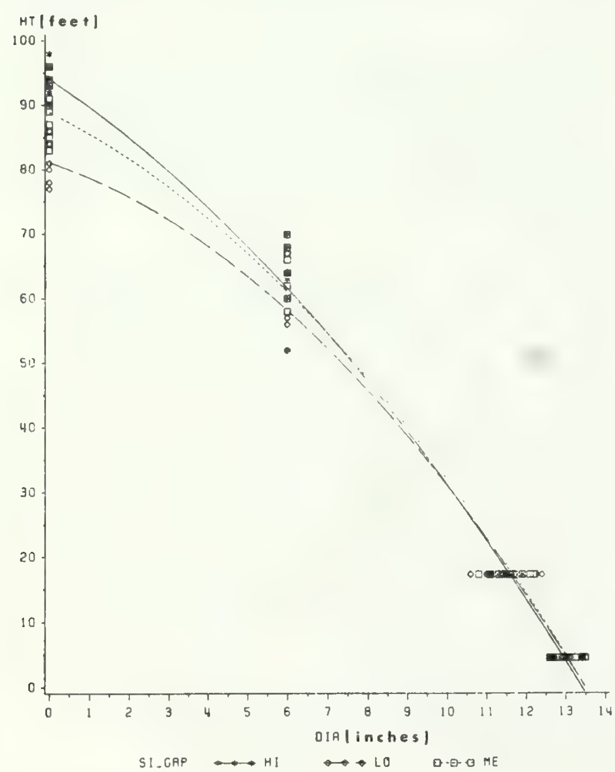


Figure 7.--Tree taper derived from four diameters and heights of 13 inch dbh loblolly pines in high, medium and low site groups of the Clemson study.

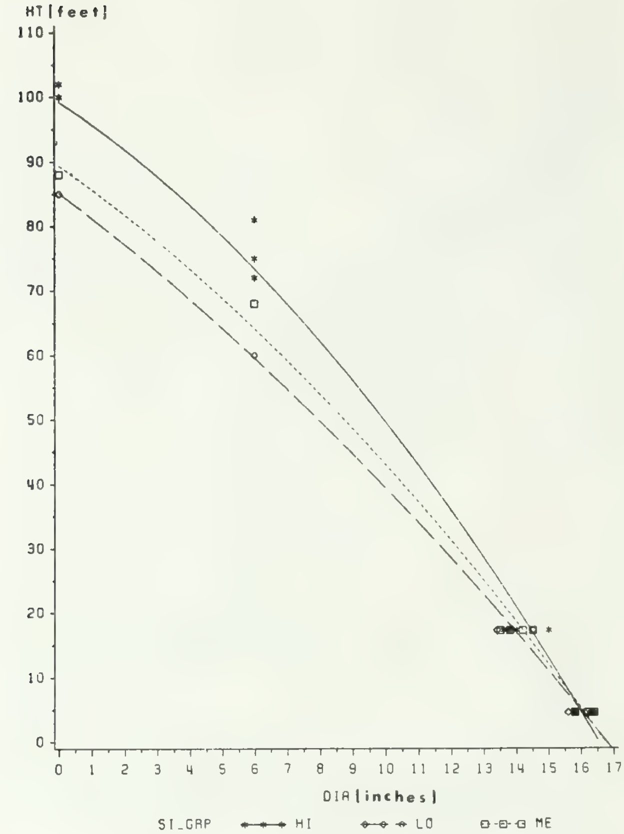


Figure 8.--Tree taper derived from four diameters and heights of 16 inch dbh loblolly pines in high, medium and low site groups of the Clemson study.

relation to height within a stand, it, therefore, mathematically increases taper or reduces form quality. This is true only if one assumes that tree form is represented by an average tree taper function such as tree diameter (in) ÷ tree height (ft) = average reduction in diameter per foot of height. The results of this study indicate that thinning does not reduce form quality, at least as measured by Girard Form Class, and in fact, may improve the form of the residual stand if low thinnings are conducted. These results also indicate that form, as measured by Girard Form Class, varies greatly within a diameter class, but is better in median diameter classes than in the smallest and largest diameter classes. Whole tree taper or form may closely follow Girard Form Class in this diameter class relationship. Site quality may play an inverse role in form quality in that tree form, as measured by Girard Form Class and crude taper curves, was best in the low site group of this study for a given tree diameter/height combination, although tree height increased for a given diameter as site quality increased, resulting in improved overall average form (reduced average taper).

An interesting postscript to this study results from an investigation of a stand of the same age and adjacent to a group of the thinning plots that was converted into a seed production area 25 years ago by cutting (thinning) it back to about 25 trees

per acre. Measurements of 39 of these trees resulted in a mean Girard Form Class of 82 and crude taper curves that indicated a no less desirable overall tree taper or form. These results serve to illustrate quite well that tree form is not a simple matter but rather is very complex, as is typical of most biological phenomena. Most assumptions about thinning and tree form have been clouded by the often-reported poor form of open-grown trees and the simple mechanistic theory of tree bole shape (Larson 1963). Perhaps recent work regarding the biological nature of tree bole form and how it comes about, McMahon (1975), Wilson and Archer (1979) and Barker (1980), provides the clue that trees, like other biological organisms, are energetically efficient and put energy into growth where it is most demanded. Thus, the distribution of cambial growth along the bole of a tree seems to be a complex response to availability of photosynthate and to stress stimuli and serves to prevent potential fracture of the stem without excessive redundancy or inefficient energy expenditure. The effects of wind sway, crown loading, live crown ratio, diameter/height ratio, site quality, stocking levels, genetic variation, and age will all have to be considered in adequately defining the response of tree form to cultural treatments. At the very least the results of this study should point out the need to adequately identify measurable tree characteristics that are more closely associated with and will more accurately predict tree taper than will diameter class, site index, and basal area per acre.

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# AN ECOLOGICAL DERIVATION OF STAND STRUCTURE IN BALANCED UNEVEN-AGED LOBLOLLY-SHORTLEAF PINE STANDS OF THE WEST GULF REGION[1/]

James M. Guldin [2/]

Abstract.--A theoretical stand structure based on crown area was compared with left-truncated negative exponential and Weibull models from three uneven-aged stands of loblolly-shortleaf (P. taeda L.-P. echinata Mill.) pine in southern Arkansas. When fit to observed merchantable distributions, the crown area model was slightly less precise than the statistical models. In a stand with balanced submerchantable structure, the crown area model was a better fit than the extended merchantable distribution statistical models; in a stand with unbalanced submerchantable structure, the reverse was true. When fit to full distributions, the statistical models were best overall, but the crown area model was best in the merchantable component. Refinements in the ecologically-based crown area model may improve the assessment of stem density, stocking, and structure of submerchantable classes in uneven-aged stands.

## INTRODUCTION

Uneven-aged silviculture embodied in the selection system clearly works well when properly applied to loblolly-shortleaf (Pinus taeda L.-P. echinata Mill.) pine stands of the West Gulf region (Reynolds 1969, Murphy and Farrar 1982a, 1983, Reynolds et al. 1984, Farrar et al. 1984, Rainey 1986). As a valid silvicultural alternative for the contemporary forester, the selection method allows the provision of income from small tracts, inexpensive rehabilitation of cutover or understocked stands, production of large high-quality timber, and the aesthetic advantage of minimal harvesting disturbance (Hann and Bare 1979, Baker 1982, Baker and Murphy 1982).

One reason for the success of the method in the loblolly-shortleaf pine type in this region is the reproductive proclivity of loblolly pine, which produces adequate seed crops annually and large crops on a 3- to 6-year cycle (Grano 1967). With regeneration success not limited by the absence of seed, pine usually becomes abundantly established in the understory gaps resulting from cutting cycle harvests. Yet, just as the shift in regulating uneven-aged stands from the volume control-guiding diameter limit methodology to the basal area - diameter limit - Q-factor (BDQ) technique was made to more objectively quantify the development of merchantable classes below the guiding diameter limit (Farrar 1981), so too should silviculturists learn more about the origin, numbers, adequacy of stocking, and dynamics of submerchantable classes. This is especially true when considering the application of uneven-aged methodology to species that are more irregular than loblolly pine in their regeneration dynamics.

Efforts to model the submerchantable structure of uneven-aged stands have been limited by the absence of data collected in submerchantable diameter classes. Assessments of regeneration adequacy are usually made using predicted values obtained by extrapolating the stem densities and Q-factor of a merchantable negative exponential model into the submerchantable classes (Moser 1976, Farrar 1981, Murphy and Farrar 1982b, Farrar 1984). A Weibull model can also be extrapolated in this fashion, but requires the inconsistent assumption of maintaining the left-truncation point in the equation and solving the equation for dbh classes less than

[1/] Paper presented at the Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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the truncation point. These procedures provide silviculturally reasonable answers, but are invalid under strict statistical assumptions.

Regeneration surveys using these extrapolation methods typically result in submerchantable stem density being assessed as either adequate or overwhelming[3]. Murphy and Farrar (1981) speculated that the lack of fit of the negative exponential distribution to merchantable uneven-aged stand structures was most pronounced in the lower diameter classes; whether this trend extends to submerchantable classes has not been explored. Further, the biological basis for applying the statistical models to uneven-aged stands has been discussed only in the broadest terms (Meyer 1952, Leak 1964, Bailey and Dell 1973).

As an alternative, it might be possible to derive the structure of a balanced uneven-aged stand based on ecological rather than statistical properties. Uneven-aged stands have their natural counterpart in old-growth stands, which are presumed to regenerate by the gap-phase regeneration strategy (Bray 1956, Oliver 1981). The mortality or harvest of a mature tree in an uneven-aged stand will create an opening in the overstory canopy; under ideal conditions, a clump of regeneration will become established beneath that opening. Given the simplest action of uneven-aged stand dynamics, only one tree in the regeneration clump will achieve the stature of the tree whose demise created the initial gap. By such logic, uneven-aged stand dynamics can be envisioned as a progressive development of horizontal projections of crown area among trees of increasing size.

Several simplifying assumptions are made in deriving this crown area model. First, the entire unit area is assumed to be exactly occupied with horizontal crown projections. Thus, no adjustment for crown overlap or underoccupancy is required. A second assumption is that the progressive development of size classes is linear with time; this implies that the horizontal crown projection in each diameter class is constant. Finally, the crown area between size classes is assumed to be equal, from the 1" class through the largest observed class in the stand. Given these assumptions, the synthesis of a crown area model of stand structure is straightforward.

Thus, this paper represents an initial effort to derive uneven-aged stand structure from rudimentary ecological considerations of uneven-aged stand dynamics.

## METHODS

Three stands were included in this study. The first is the Selection #2 stand of the Methods of Cutting Study on the Crossett Experimental Forest, located in Ashley County, Arkansas; the diameter distribution in this stand ranges from 4" to 31" (Farrar 1981). The two remaining stands are located on lands managed by Deltic Farm and Timber Co., Inc., a subsidiary of Murphy Oil Co., of El Dorado, Arkansas. Both of these stands represent full diameter distributions, which include submerchantable as well as merchantable classes. Deltic Stand 1 is 160-acre uneven-aged stand located in Union County, Arkansas. This stand received a cutting-cycle harvest in the spring of 1986; the stand was sampled (at roughly a 10% intensity) in the summer of 1986 to assess logging damage in the residual stand. Diameter classes in this stand range from 1" to 20". Deltic Stand 2 is a 2.5-acre study area within a 40-acre management unit, also in Union County, Arkansas. On this study area, all stems greater than 0.5" were mapped and measured. Diameter classes range from 1" to 22". Crown radii along cardinal directions were taken from a sample of 31 trees in Stand 2.

A regression of crown area (determined by the quarter-ellipse summation method) versus dbh was developed using the crown radius data from Stand 2, as follows:

$$CA = 10.321737 * D + 1.986642 * D^2,$$

where CA is the horizontal projection of crown area of a given tree, and D is the diameter at breast height for that tree ($R^2$= 96.9 percent, $F_{(2,29)}$ = 468.993, $P < 0.000$). In each stand, the crown area for each diameter class was determined by dividing the area of an acre by the number of diameter classes (from the 1" class through the class containing the largest tree). The regression equation was used to determine the crown area of a single tree at the midpoint of each dbh class, and the stem density per acre in each dbh class was obtained using a straightforward expansion factor calculation.

Left-truncated negative exponential and Weibull models were also fit to each stand. Goodness of fit for these models was evaluated using root mean squared deviation and fit index, formulas for which are presented in Table 1 (Farrar et al. 1984). Negative exponential models were tested by iterative 0.001-Q factors; the final models selected were those which minimized root mean squared deviation. Weibull models were fit using the maximum likelihood method (Zutter et al. 1982).

The Crossett Selection #2 stand was fit with a left-truncation point of 3.5". Each Deltic stand was fit with left-truncation points of 3.5" (merchantable distribution models) and 0.5" (full distribution models). The Deltic stands were also evaluated by extension of the merchantable models into the submerchantable classes (extended merchantable distribution models)

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3/ Farrar, R. M.; Guldin, J.M. Unpublished data, USDA Forest Service, Monticello, AR.

TABLE 1. Goodness of fit indices for comparisons between observed and expected data.

a. Root Mean Squared Deviation, RMSD

$$\mathrm{RMSD} = \sqrt{(1/n) \sum_{i=1}^{n} (Yi - \hat{Y}i)^2}$$

b. Fit Index, FI

$$\mathrm{FI} = 1 - \left[ \sum_{i=1}^{n} (Yi - \hat{Y}i)^2 / \sum_{i=1}^{n} (Yi - \bar{Y})^2 \right]$$

where n = number of diameter classes being evaluated

$Yi$ = observed number in the $i^{th}$ diameter class

$\hat{Y}i$ = expected number in the $i^{th}$ diameter class

$\bar{Y}$ = mean observed number of stems per diameter class

## RESULTS

### Merchantable distribution models

In the Crossett Selection #2 stand, all three models fit the observed stand structure fairly closely (Figure 1). The crown area model predicts more trees than the other models in the smallest (4"-5") and largest (25"+) dbh classes, but predicts fewer trees than the others in the 6"-20" classes. The statistical models fit the observed data most precisely (Table 2a).

All three methods provide reasonable approximations of the merchantable component of Deltic Stand 1 (Figure 2). The crown area model is best through a fairly broad range of the sawtimber classes, but overestimates the observed numbers of the largest sawtimber classes. All three models predict fairly similar stem densities from the 4" through the 11" classes and show a good fit of the observed data (Table 2b), with the range of the fit index less than one percent among the three models.

For the slightly irregular Deltic Stand 2, reasonable approximations of the observed data

TABLE 2. Goodness-of-fit results for comparisons of merchantable distribution models.

| MODEL | RMSD | FI |
|---|---|---|
| a. Crossett Selection #2 | | |
| Negative exponential | 1.0413 | 0.9498 |
| Weibull | 1.3422 | 0.9164 |
| Crown Area | 1.7434 | 0.8618 |
| b. Deltic Stand 1 | | |
| Negative exponential | 2.2237 | 0.9233 |
| Weibull | 2.0127 | 0.9267 |
| Crown Area | 2.2917 | 0.9193 |
| c. Deltic Stand 2 | | |
| Negative exponential | 3.2465 | 0.6844 |
| Weibull | 2.9234 | 0.7233 |
| Crown Area | 3.1406 | 0.7173 |

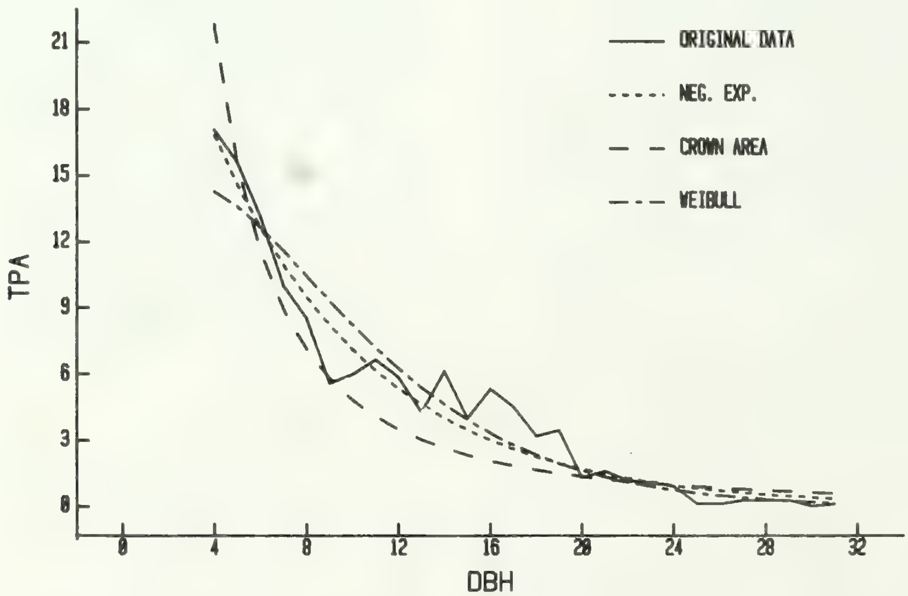


Figure 1. Merchantable distribution models versus original data, Crossett Selection #2 stand. TPA = trees per acre; DBH = diameter at breast height.

are again obtained with all three models (Figure 3), though with slightly less precision (Table 2c). All three models are fairly uniform in the 8" class and larger, but the crown area model appears to more precisely predict the high stem density in the 4" class, which possibly accounts for its better fit than the negative exponential model.

## Extended merchantable distribution models

In Deltic Stand 1, the extended merchantable statistical models fit the observed data better than the crown area model (Figure 4 and Table 3a). This is attributed to the even-aged character of the submerchantable classes, as judged by their bell-shaped normal curve

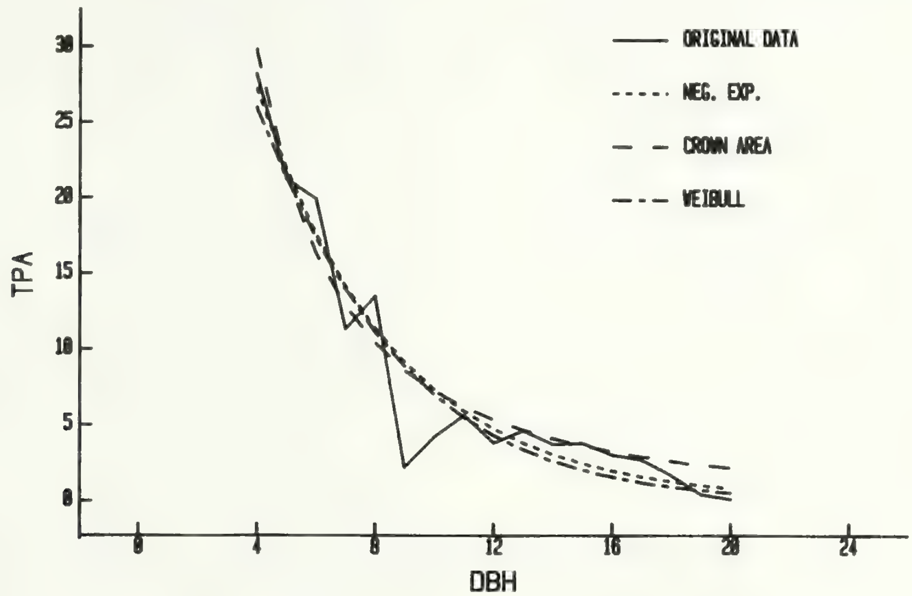


Figure 2. Merchantable distribution models versus original data, Deltic Stand 1. TPA = trees per acre; DBH = diameter at breast height.

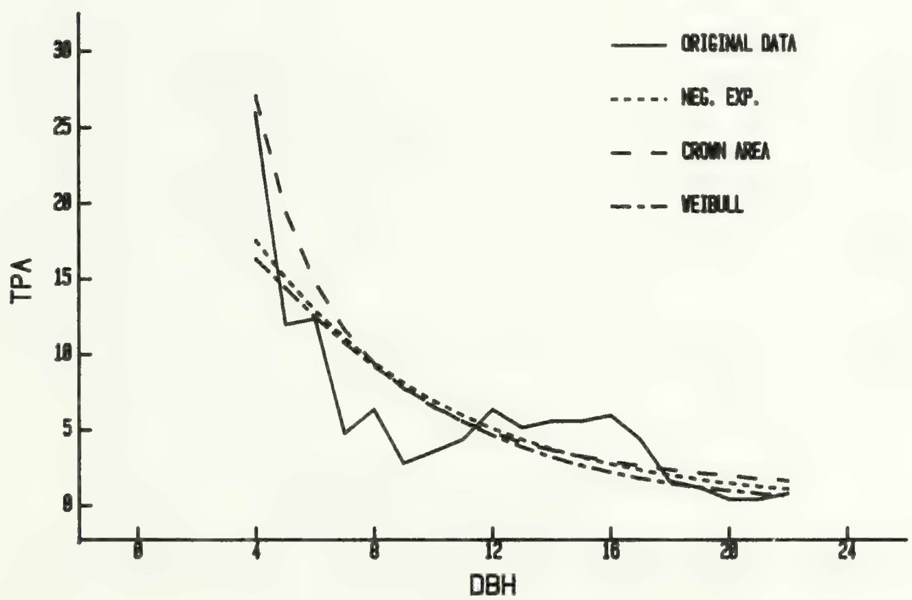


Figure 3. Merchantable distribution models versus original data, Deltic Stand 2. TPA = trees per acre; DBH = diameter at breast height.

form. The even-aged trait is probably due to the development of regeneration following the 1979 cutting cycle harvest, coupled with the absence of regeneration (due to the absence of cutting) in the years between 1979 and 1986. Regeneration is expected in this stand in the fall of 1986, following the cutting-cycle harvest of the preceding spring, and this generation of reproduction will probably re-establish the uneven-aged character of decreasing numbers through the submerchantable classes. If the one-inch class is not included in the goodness of fit test, the fit of the crown area model (0.7110) is better than the negative exponential (0.7088) but poorer than the Weibull (0.7487); if both the one- and two-inch classes are ignored, the fit of the crown area model (0.7337) is better than either the Weibull (0.6948) or the negative exponential (0.6506) models. This suggests an age-related character to submerchantable structure in uneven-aged stands, which existing theory on uneven-aged structure fails to address.

Table 3. Goodness-of-fit results for comparisons of extended merchantable distribution models.

| MODEL | RMSD | FI |
|---|---|---|
| a. Deltic Stand 1 | | |
| Negative exponential | 12.8581 | 0.6346 |
| Weibull | 12.5745 | 0.6371 |
| Crown area | 33.6321 | -1.2818 |
| b. Deltic Stand 2 | | |
| Negative exponential | 46.1537 | 0.2183 |
| Weibull | 42.6342 | 0.1836 |
| Crown area | 21.8272 | 0.8107 |

Deltic Stand 2 is more balanced in its submerchantable structure, and the crown area model fits much better than either the Weibull or the negative exponential (Figure 5 and Table 3b). The extended merchantable statistical models drastically underestimate submerchantable stem density. This suggests that the traditional method of evaluating regeneration adequacy in uneven-aged stands may be unreliable, and has the potential to result in understocking of the submerchantable classes.

## Full distribution models

When full distribution models are fit to the observed data in Deltic Stands 1 and 2 (Figures 6 and 7, respectively), the statistical models give better results than the crown area models (Tables 4a and 4b). In Deltic Stand 1, this is due to the previously-noted overestimation of the 1" class by the crown area model. In Deltic Stand 2, the crown area model underestimates the observed data in the submerchantable classes more than the statistical models.

However, in both Deltic stands, the full-distribution statistical models overestimate the observed number of pulpwood-sized stems, most prominently in Deltic Stand 2. When the merchantable components of the three full-distribution models are compared to the observed merchantable distributions, the crown-area model has the best fit (Tables 5a and 5b, respectively). This will result in better volume estimates with the crown area model than with the full-distribution statistical models.

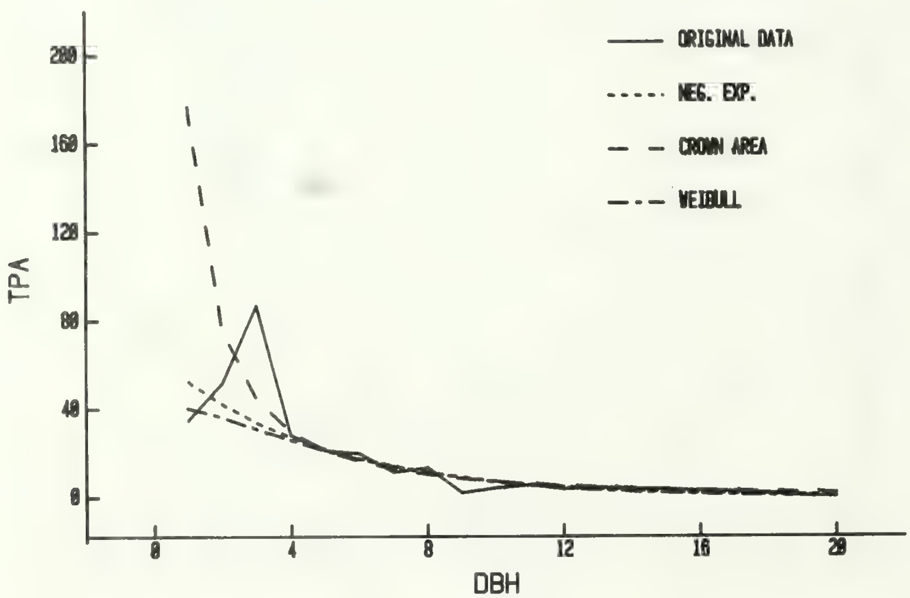


Figure 4. Extended merchantable distribution models versus original data, Deltic Stand 1. TPA = trees per acre; DBH = diameter at breast height.

## CONCLUSIONS

Crown area derivation appears to be a promising technique for characterizing submerchantable stand structure in uneven-aged stands of loblolly-shortleaf pine in the West Gulf region. A simple crown area approach produced models of merchantable stand structure which were only slightly less precise than fitted left-truncated negative exponential and Weibull statistical models. Further, in a stand with a balanced submerchantable structure, the crown area model provided a dramatically better fit of submerchantable stem density than the extended merchantable distribution statistical models. However, in a stand of unbalanced submerchantable structure, the reverse was true. Finally, full-distribution statistical models

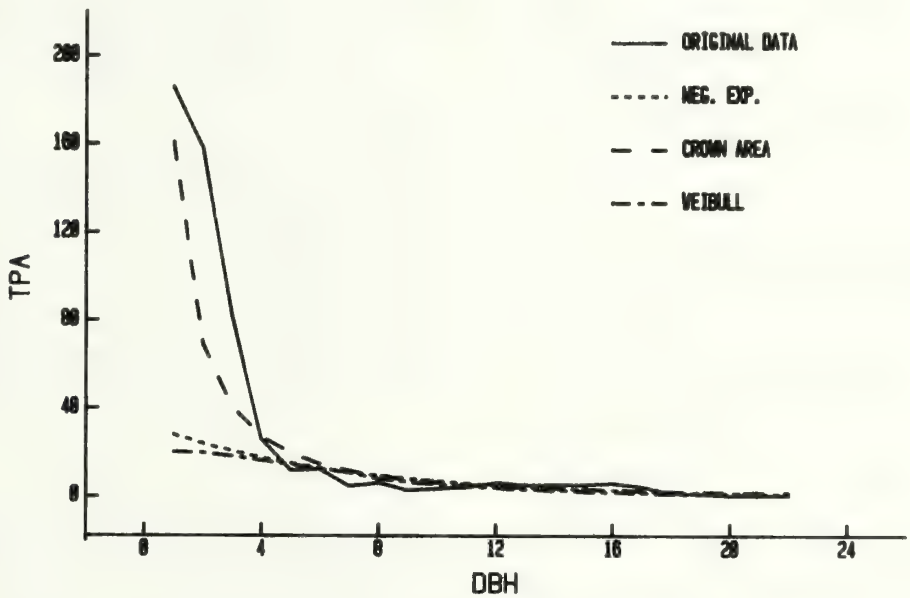


Figure 5. Extended merchantable distribution models versus original data, Deltic Stand 2. TPA = trees per acre; DBH = diameter at breast height.

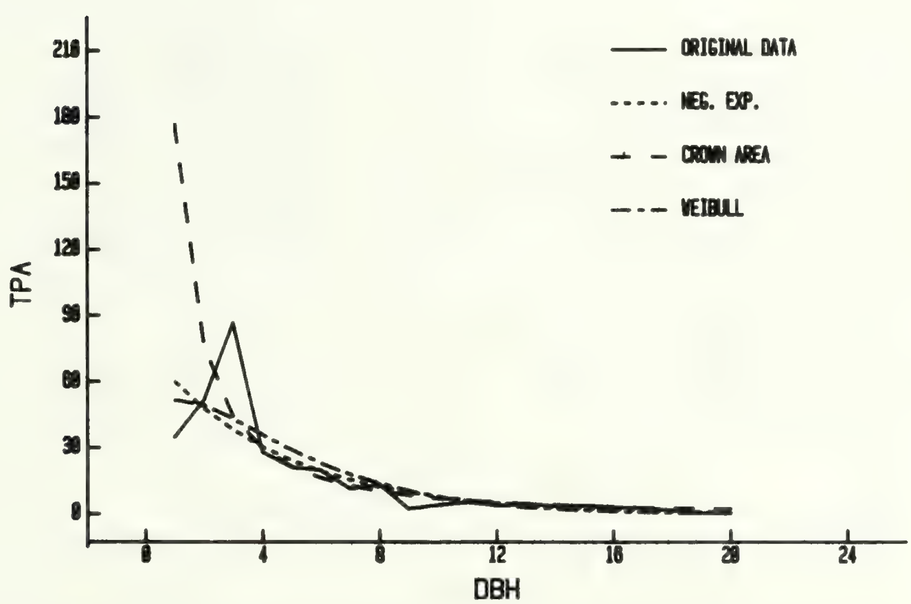


Figure 6. Full distribution models versus original data, Deltic Stand 1. TPA = trees per acre; DBH = diameter at breast height.

Table 4. Goodness-of-fit results for comparisons of full distribution models.

| MODEL | RMSD | FI |
|---|---|---|
| a. Deltic Stand 1 | | |
| Negative exponential | 12.5278 | 0.6502 |
| Weibull | 10.8655 | 0.7302 |
| Crown area | 33.6321 | -1.2818 |
| b. Deltic Stand 2 | | |
| Negative exponential | 15.1464 | 0.9084 |
| Weibull | 13.2642 | 0.9266 |
| Crown area | 21.8272 | 0.8107 |

Table 5. Goodness-of-fit results for comparisons of merchantable component of full distribution models.

| MODEL | RMSD | FI |
|---|---|---|
| a. Deltic Stand 1 | | |
| Negative exponential | 2.5683 | 0.8992 |
| Weibull | 3.9132 | 0.7701 |
| Crown area | 2.2917 | 0.9193 |
| b. Deltic Stand 2 | | |
| Negative exponential | 14.8400 | -1.8607 |
| Weibull | 7.1601 | -0.2886 |
| Crown area | 3.1406 | 0.7173 |

provided a better overall fit than the crown area model, but the crown area model fit better in the merchantable component.

This simple crown area model represents a rudimentary ecological derivation of uneven-aged stand dynamics. The approach is consistent with the current understanding of gap-phase regeneration strategies upon which the regeneration ecology of uneven-aged stands is based. In this sense, the model has a conceptual appeal over statistical representations of uneven-aged structure, which have no readily-discernible ecological basis.

Silvicultural implications of this approach are in the quantification of regeneration success in submerchantable classes. Clearly, it is important to know how many stems one might expect in a given size class before one pronounces an observed number as adequate. Traditional methods of determining adequate numbers of submerchantable classes, involving submerchantable extensions of merchantably based statistical models, appear to seriously underestimate the number of trees required to maintain a balanced uneven-aged stand. Crown area models of stand structure may provide for more accurate regeneration assessment through improved methods of evaluating both stem density and stocking in submerchantable classes.

## ACKNOWLEDGEMENTS

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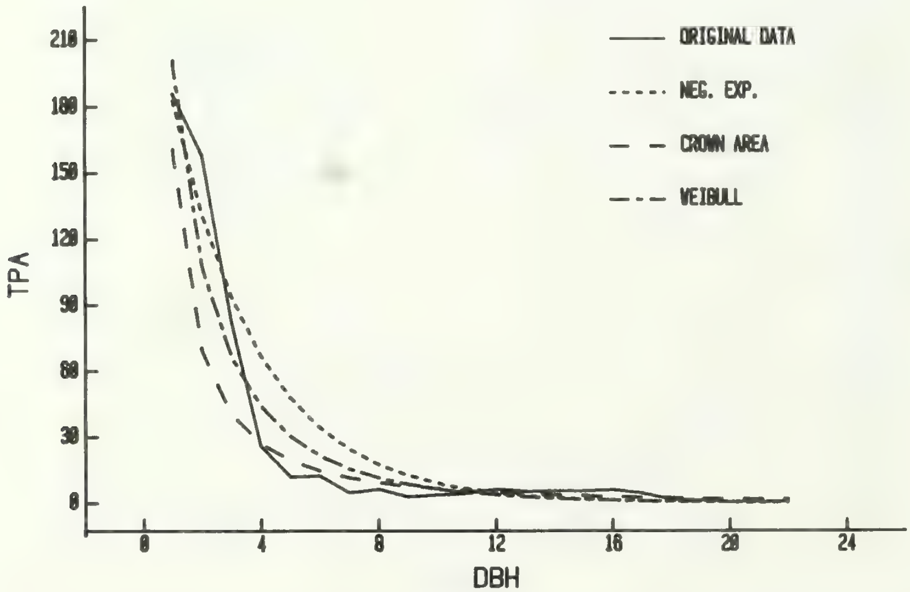


Figure 7. Full distribution models versus original data, Deltic Stand 2. TPA = trees per acre; DBH = diameter at breast height.

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# GROWTH AND YIELD OF SWEETGUM-CHERRYBARK OAK MIXTURES[1]

(ABSTRACT)

Thomas G. Matney, John D. Hodges, and Alfred D. Sullivan[2]

Sweetgum-cherrybark oak mixtures are widely distributed on the minor stream bottoms of Mississippi and Alabama, and it is one of the most important hardwood types found in these states. This paper describes a compatible growth and yield model developed to aid foresters involved in the management of these stands. The model uses mixtures of diameter distributions, compatible with each stand component's mean and quadratic mean diameters. Subsequent merchantable board feet and cubic foot volumes are derived by grade using grade distribution tables and merchantable height predictors.

[1]Paper presented at Fourth Biennial Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2]Mississippi State University, Mississippi State, MS

# A NEW AND SIMPLE METHOD FOR MODELING STAND AND STOCK TABLES[1/]

Bruce E. Borders and Ray A. Souter[2/]

Abstract.--A simple method for characterizing stand and stock tables is presented which does not rely on pre-defined mathematical probability distributions. A set of percentile points is used to characterize the distribution of interest. By assuming a uniform distribution of tree frequency between adjacent percentile points and using linear interpolation, whole stand measures of surviving trees/acre, total volume/acre, and merchantable volume/acre can be proportioned among any desired diameter size classes. The flexibility of the method is such that any distribution shape can be reproduced (e.g. reverse-j, mound-shaped, and multi-modal distributions). This simple and flexible method was found to fit observed stand and stock tables extremely well for thinned natural loblolly pine stands and thus it holds great promise for future modeling efforts.

## INTRODUCTION

Traditional diameter distribution models make use of statistical probability density functions (pdf) to reproduce stand tables. The exponential pdf has been used to model uneven-aged stands (Meyer and Stevenson, 1943; Meyer, 1952; Schmelz and Lindsey, 1965). Many pdf's, including the log-normal, normal, gamma, beta, Johnson's Sb, and weibull have been used to model unimodal mound shaped distributions characteristic of even-aged stands. There are no underlying biological precepts that indicate why one pdf should be preferred to another. The weibull has come to be the pdf of choice due to its high degree of shape flexibility and closed form cumulative distribution function (Bailey and Dell, 1973).

A limitation of using pdf's to model stand tables is that they are all unimodal. Several studies have shown that these unimodal pdf's are not always adequate for modeling stand tables (Murphy and Farrar, 1981; Cao and Burkhart, 1984). Below, we present a method for modeling stand tables that does not require a predefined pdf. This method, referred to as the percentile method, is very simple and very flexible (i.e. it can be used to reproduce reverse-j shaped stand tables, as well as unimodal and multimodal stand tables). In addition to reproducing stand tables, we show how, with slight modification, the percentile method can be used to partition a per-acre estimate of volume directly into size classes without first obtaining a stand table.

## STAND TABLES

Assume we have a per-acre stand table with N trees. Define the $i^{th}$ size class with a lower diameter at breast height (dbh) limit of $D_{Li}$ and an upper dbh limit of $D_{Ui}$. Then if there are $N_i$ trees uniformly distributed in each of k size classes (i.e. i=1,2,...,k) we can define an empirical pdf (epdf)

$$f(D) = \begin{cases} N_i/N/(D_{Ui} - D_{Li}) & D_{Li} < D < D_{Ui} \\ 0 & \text{elsewhere} \end{cases} \qquad (1)$$

where,

D = diameter at breast height (dbh),
N = number of trees per acre,
$N_i$ = number of trees per acre in the $i^{th}$ size class,
$D_{Ui}$ = upper dbh limit in the $i^{th}$ size class,
$D_{Li}$ = lower dbh limit in the $i^{th}$ size class.

Note that the size classes can be of any width (i.e. one-inch, two-inch, product classes, etc...).

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

2/ Assistant Professor at the University of Georgia in Athens, Georgia and Mathematical Statistician at the USFS Pacific Northwest Forest Experiment Station in Portland, Oregon, respectively.

The $j^{th}$ dbh percentile, say $P_j$, of this epdf for which a tree has dbh less than $P_j$ with probability $t_j$ is

$$F(P_j) = \int_{-\infty}^{P_j} f(D)dD = t_j \qquad (2)$$

When the percentile $P_j$ occurs in the $k^{th}$ size class, $P_j$ is calculated as

$$P_j = (t_j - \sum_{i=1}^{k-1} (N_i/N))(D_{Uk}-D_{Lk})(N/N_k) + D_{Lk} \qquad (3)$$

where,

all symbols are as defined above.

Using equation 3 we can calculate several percentiles across the range of dbh values in the observed stand table. Once we have obtained these percentiles, we can closely reproduce the stand table from which the percentiles were calculated. We simply assume that trees are uniformly distributed between adjacent percentiles. This defines a density function and associated cumulative distribution function similar to equations 1 and 2. With this cumulative distribution function we obtain the following formula for calculating $N_k$, the number of trees per acre in size class k

$$\begin{aligned} N_k = \{&[t_i-t_{i-1}]\ [P_i-D_{Lk}]/[P_i-P_{i-1}] \\ &+ [t_{j+1} - t_j]\ [D_{Uk} - P_j]/[P_{j+1} - P_j] \\ &+ [t_j - t_i]\}N \end{aligned} \qquad (4)$$

where,

$P_{i-1} < D_{Lk} < P_i$,

$P_j < D_{Uk} < P_{j+1}$,

and all else is as defined above.

Equation 4 will not reproduce the observed stand table exactly, the method tends to even out differences between consecutive size classes. However, if all size class limits were percentiles of the system, then an exact reproduction would occur.

Thus, we have defined a method which can reproduce any stand table given a set of dbh percentiles from that stand table. For modeling purposes we must be able to predict these percentiles from stand characteristics. A system of percentile prediction equations can be formulated using the following construct

$$P_D = f(\text{stand characteristics})$$

$$P_{D+i} = f(P_D, \text{stand characteristics}) \qquad (5)$$

where,

$i = -j, -j+1, \ldots, -1, 1, 2, \ldots, 1$

$P_D$ = percentile selected to "drive" the prediction system; generally the percentile that can be predicted with the highest confidence,

$P_{D+i}$ = other percentiles of the system, which due to constraints, are directly or indirectly related to $P_D$ such that there are j percentiles less than $P_D$ and 1 percentiles greater than $P_D$.

The individual equations are constructed so that percentile estimates are monotonic increasing with $P_{D-j}$ the minimum and $P_{D+1}$ the maximum. Souter (1986) developed a percentile prediction system for a set of 12 percentiles ($0^{th}, 5^{th}, 15^{th}, \ldots, 95^{th}, 100^{th}$) for natural stands of thinned loblolly pine using construct 5. He then used this prediction system and equation 4 to reproduce the observed stand tables. He found that the percentile method performed very well on these unimodal and irregularly shaped multi-modal stand tables.

## STOCK TABLES

It is possible to obtain a predicted stock table using a stand table obtained with the percentile method as described above. We simply use a height-diameter function and a volume equation to obtain the volume of the average tree in each size class and multiply this volume by the number of trees in each size class (i.e. using traditional diameter distribution modeling methodology). This approach is sound and can be used without apprehension. However, we would like to present an alternative method below.

Individual tree volume can be thought of as being proportional to dbh squared times height. Within a dbh size class, height can be taken to be proportional to dbh. Thus we can say that within a size class tree volume is proportional to dbh cubed, with a different proportionality constant for each size class. Symbolically we write

$$V = k_1\ D^2H$$

$$H = k_2\ D$$

$$\rightarrow V = k_3D^3$$

where,

V = tree volume (merchantable or total),
D = dbh,
H = total tree height,

$k_1$, $k_2$, $k_3$ are proportionality constants.

Now, if we assume that volume is proportional to dbh cubed and that trees are uniformly distributed within a size class, we can define the following empirical pdf for per-acre volume

$$f(D) = \begin{cases} 4\, V_i\, D^3/(D_{Ui}^{\,4} - D_{Li}^{\,4})/V & D_{Li}<D<D_{Ui} \\ 0 & \text{elsewhere} \end{cases} \qquad (6)$$

where,

$i = 1,2,\ldots,k,$
$V_i$ = volume in the $i^{th}$ size class,
$V$ = per-acre volume,
$D$ = dbh,
$D_{Ui}$ = upper dbh limit in the $i^{th}$ size class,
$D_{Li}$ = lower dbh limit in the $i^{th}$ size class.

The epdf can be used to calculate percentiles, $P_j$, such that $t_j$ percent of the volume in the stock table falls below dbh value $P_j$. These percentiles are calculated in a similar fashion to those for stand tables. When $P_j$ falls in the $k^{th}$ size class, it is defined as

$$P_j=[t_j-\sum_{i=1}^{k-1}(V_i/V))(D_{Uk}^{\,4}-D_{Lk}^{\,4})(V/V_k)+D_{Lk}^{\,4}]^{\frac{1}{4}} \qquad (7)$$

where,

all symbols are as defined above.

Thus, we can define a set of percentiles for a stock table using equation 7. Now if we assume that trees are uniformly distributed between adjacent percentiles we can define an epdf, similar to 6, along with its associated cumulative distribution function. Using this epdf, volume in the $k^{th}$ size class is defined as

$$\begin{aligned} V_k = \{ & (t_i-t_{i-1})(P_i^{\,4}-D_{Lk}^{\,4})/(P_i^{\,4}-P_{i-1}^{\,4}) \\ & + (t_{j+1}-t_j)\ (D_{Uk}^{\,4}-P_j^{\,4})/(P_{j+i}^{\,4}-P_j^{\,4}) \\ & + (t_j - t_i)\}\ V \end{aligned} \qquad (8)$$

where,

$P_{i-1} < D_{Lk} < P_i$,

$P_j < D_{Uk} < P_{j+1}$,

and all else is as defined above.

Just as with stand tables, we must develop a prediction system for volume percentiles defined in equation 7. This is accomplished using construct 5. Souter (1986) fit a percentile prediction system for a set of 12 volume percentiles ($0^{th}$, $5^{th}$, $15^{th}$, ..., $95^{th}$, $100^{th}$) for natural stands of loblolly pine. He used the percentile method to predict the unimodal and multimodal stock tables. He found that the fits were very good.

## DISCUSSION

The percentile method can be used for modeling both stand and stock tables. The method is simple to apply and has great shape flexibility. It can be used in place of probability density functions, such as the weibull, in traditional diameter distribution models. In this instance, the shape flexibility (i.e. the ability to reproduce reverse-j, unimodal, and multimodal stand tables) is a great advantage over pdf models.

We have shown how it is possible to use the percentile method to obtain a stock table without first estimating a stand table. We simply break a per-acre estimate of volume into dbh size classes. Fit statistics with empirical data show that this method can be used with confidence when only the stock table is of interest.

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IN SEARCH OF AN IMPROVED SAWTIMBER STAND VOLUME FUNCTION[1/]

Robert M. Farrar, Jr. and Paul A. Murphy[2/]

Abstract. -- The Schumacher stand volume function is commonly fitted to predict stand volumes in studies of growth and yield in natural stands of southern pine, and it usually works very well for cubic-foot volumes. However, it usually does not perform as well for board-foot volumes, particularly for those by the Doyle log rule. This paper presents a recent history of developments in stand-level volume and volume growth modeling, including use of the Schumacher function, and the results of attempts to improve this function for Doyle board-foot predictions.

## INTRODUCTION

Stand-level models for growth and yield prediction produce lump-sum or aggregated estimates of stand production in terms of basal area and volume. Compared to diameter-distribution or individual-tree models, they produce less detail but are entirely adequate for many purposes. At an elementary level, management regimes can be simulated by reference to prepared tables or the functions can be entered into a programmable calculator. They also run very efficiently on microcomputers in either electronic spreadsheets or custom application programs. Stand-level models usually operate on the input stand variables age (or elapsed time), site index, and basal area. They commonly consist of two principal components: (1) basal area driver(s) that project a current basal area to a future value and (2) stand volume function(s) that convert stand age, site index, and basal area into stand volume by utilizing either current or future values of these input variables.

## RECENT HISTORY OF DEVELOPMENTS

To best understand where we are in stand-level modeling, we can review its recent history to see how current formulation of the components of a stand-level system came about.

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The first major development after normal yield tables was the variable-density yield prediction system of MacKinney and Chaiken (1939), in which stand volume is not only a function of age and site index but also of varying stand density. They used a modification of the "Schumacher yield function," a form first suggested by Schumacher (1939), and applied it to predict stand volume for second-growth loblolly pine. The authors of this paper prefer the term "stand volume function," because yield implies not only the standing volume but also the volume harvested from a stand up to that time. The current common formulation of this function is:

$$\ln(V) = b_0 + b_1(S) + b_2(A^{-1}) + b_3(\ln(B)) \quad \text{or}$$

$$V = \exp[b_0 + b_1(S) + b_2(A^{-1}) + b_3(\ln(B))], \quad \text{where}$$

ln = natural or base e logarithm,

V = stand volume per acre (cubic feet or board feet),

$b_i$ = parameters to be estimated,

S = site index (feet),

A = stand age (years),

B = basal area per acre (square feet), and

$\exp[x] = e^x$.

It is commonly fitted to stand volumes at both the start and end of growth periods so that volumes can be estimated at any point in time. Both cubic- and board-foot volumes are estimated with this formulation.

The next major development was a system of compatible growth and yield (stand volume) models developed by Clutter (1963) for thinned natural loblolly pine in the Southeast. Clutter reasoned that a stand volume function should be compatible

with a volume growth function and that its derivative should produce a volume growth function. Conversely, the growth function integral should be the stand volume function. In his system, Clutter used the above Schumacher function to predict current total cubic-foot stand volume and developed a volume projection function, which incorporated a basal area projector, to predict future stand volume. This basic approach has been used since then in some form for most stand-level modeling efforts. The system provided the first comprehensive system by which the growth and production could be simulated for thinned (or unthinned) stands for various periods, density regimes, and rotations.

However, growth for a period estimated by the volume projection function did not exactly match growth obtained by the difference between the stand volume function at the start and end of the period. This problem was solved by Sullivan and Clutter (1972) in their simultaneous stand growth and volume prediction system, although the volume estimates were still in terms of only total cubic feet.

The first application of the simultaneous system that presented a sawtimber predictor in addition to a cubic-foot volume predictor was the system by Brender and Clutter (1970) for thinned natural loblolly pine in the Georgia Piedmont. Here the Schumacher function was employed to provide stand volume equations in terms of stand age, site index, and merchantable basal area for both merchantable cubic-foot and International 1/4-inch board-foot volumes. Future stand volumes were estimated via basal area projectors (drivers) incorporated into volume projection equations.

This simultaneous system produces reasonable estimates of sawtimber volume and growth. But because both the merchantable and sawtimber volume predictors employ only merchantable basal area, there is no opportunity to manipulate the sawtimber basal area and sawtimber volumes in thinning simulations. Therefore, for any age and site index, the merchantable basal area dictates one sawtimber volume; yet, depending on stand history, there could be a number of sawtimber basal areas and volumes for a given merchantable basal area (more about this later). Also, there is no control over the sawtimber cuts in thinning regime simulations. One can specify desirable residual merchantable basal areas and obtain resulting operable cubic-foot volume cuts, but the attendant estimates of board-foot cut may or may not be operable. Also, the sawtimber volume estimates are "imbedded" in the merchantable volume estimates which cannot be separated into estimates of sawtimber and sub-sawtimber (pulpwood).

Other approaches using simultaneous-type systems with single total or merchantable basal area drivers have attempted to produce estimates of sawtimber volumes and growth in addition to total and/or merchantable cubic-foot values. Bennett (1970, 1980) employed the Schumacher function to estimate merchantable cubic-foot stand volumes but used another function employing merchantable basal area and cubic-foot volume to estimate International 1/4-inch board-foot volumes for thinned even-aged natural slash pine stands in the Southeast. Farrar (1979) also used the Schumacher function to predict total cubic-foot volumes for stands of thinned even-aged natural longleaf pine in the East Gulf area but employed ratio estimators to predict a series of merchantable and sawtimber volume values from total cubic-foot volume. He first fitted a series of Schumacher stand volume functions, but some intersected and produced anomalous results. He could see no ready way to constrain various volume estimates to be separate other than to use ratio estimators.

Bennett's system suffered from the same problem as the Brender and Clutter system with an additional quirk -- often at young ages, slightly more sawtimber volume would be predicted in the residual stand after a simulated cut than was predicted to be present in the stand before the cut. This is an artifact of the equation used to predict the sawtimber volumes. This function apparently does a good job of predicting the sawtimber volume for the static conditions of a given stand age, site index, and merchantable density but can produce such anomalous results when put into a simulated thinning regime context. The problem occurs at young ages, is usually minor, and disappears as age increases. It can be practically handled by ignoring it, but in fact it is a deficiency in formulation.

The ratio-estimator stand-volume equation system of Farrar (1979) for natural longleaf pine was also driven by a single basal area predictor. It did provide estimates of total, merchantable, and sawtimber volumes that allowed, by subtraction, estimates of nonmerchantable, pulpwood, and sawtimber volumes and growth. However, it also had the problem of anomalous predictions for sawtimber cuts at young ages. Again, this minor problem disappeared with increasing age but remained a formulation deficiency.

Thus, to successfully and logically predict the stand volume components of interest in a system that would provide for manipulation of the density components and produce logical results in thinning simulations, some new formulations were needed. The simultaneous-type systems seemed to be the best basic approach because they appeared to work well for total or merchantable stand volumes and growth. Such a system consists of two principal parts: (1) the stand volume function and (2) the basal area driver. Both parts were inspected for opportunities for improvement.

The Schumacher stand volume model appeared to be adequate. No obvious way to improve it could be determined other than to possibly have a function for merchantable cubic-foot volume that

Table 1.--Evaluation of a Schumacher function for Doyle volume fitted with different basal area variables, natural loblolly pine

| Variable | n[1] | $\bar{y}$[2] | Criterion | | | | |
|---|---|---|---|---|---|---|---|
| | | | F.I.[3] | $\bar{d}$[4] | RMSd[5] | $\overline{\%d}$[6] | RMS%d[7] |
| Merch. basal area | 268 | 3707 | .76 | -27 | 1616 | 36 | 141 |
| Sawt. basal area | 268 | 3707 | .86 | -25 | 1232 | 7 | 40 |

[1] n = number of observations.

[2] $\bar{y}$ = mean observed Doyle stand volume per acre.

[3] F.I. = Fit Index = $1-[\sum(\hat{y}_i-y_i)^2/\sum(y_i-\bar{y})^2]$.

[4] $\bar{d}$ = mean deviation = $1/n\sum(\hat{y}_i-y_i)$.

[5] RMSd = root mean squared deviation = $\sqrt{1/n\sum(\hat{y}_i-y_i)^2}$.

[6] $\overline{\%d}$ = mean percent deviation = $1/n\sum[(\hat{y}_i-y_i)/y_i](100)$.

[7] RMS%d = root mean squared percent deviation

$$=\sqrt{1/n\sum[(\hat{y}_i-y_i)/y_i]^2}\ (100),$$

where $y_i$ = observed value and $\hat{y}_i$ = predicted value.

would employ merchantable basal area as an independent variable and a function for sawtimber volume that would employ sawtimber basal area. It seemed that the sawtimber volume should be better related to sawtimber basal area than to merchantable basal area, and this was verified. Table 1 shows the results of fitting the Schumacher function to a natural loblolly pine data set of Doyle stand volumes by alternatively using each measure of basal area as an independent variable.

The next step was to modify the basal area driver to capitalize on this information. To use separate measures of basal area in the separate stand volume functions, it seemed that two separate but interrelated drivers were needed -- one for merchantable basal area and one for sawtimber basal area. If successful, this might result in a merchantable stand volume function (cubic feet) coupled with a merchantable basal area driver and also a sawtimber stand volume function (cubic feet or board feet) coupled with a sawtimber basal area driver in a consistent system to predict volumes and growth for both the merchantable stand and the sawtimber portion of the stand.

In a first attempt to develop such a dual system, Murphy and Farrar (1982) worked with a data set from uneven-aged loblolly/shortleaf pine stands on nominal site index 90 in the West Gulf area and employed the simultaneous-type models of Moser and Hall (1969) as a basis. First, the authors developed a merchantable basal area driver and a merchantable cubic-foot stand volume equation. Then a sawtimber basal area driver, which was constrained to be equal to or less than the merchantable basal area driver, was developed along with sawtimber stand volume equations for cubic feet and board feet by the Doyle, International 1/4-inch, and Scribner log rules (Murphy and Farrar 1983, Farrar and others 1984). This system worked well and had none of the problems associated with the previous attempts to predict merchantable and sawtimber volumes and growth. It worked so well that it was extended to prediction systems for natural even-aged stands of shortleaf pine in the West Gulf (Murphy and Beltz 1981, Murphy 1982), loblolly pine in the West Gulf (Murphy 1983a, 1983b), and longleaf pine in the East Gulf (Farrar 1985). It was again re-employed for uneven-aged stands of shortleaf pine in the West Gulf (Murphy and Farrar 1985).

These systems permit simulations of thinning regimes in which the merchantable (or total) basal area and the sawtimber basal area can be manipulated independently under the logical constraint that the sawtimber is always a subset of the merchantable (or total) basal area. In other words, the sawtimber basal area must always be less than or equal to the merchantable basal area. The basal area drivers were formulated and fitted under this constraint, but there is no mechanism to prevent their being misapplied. For example, in a thinning regime simulation, there is nothing to prevent the user from erroneously specifying a cut of 10 square feet of merchantable basal area and 20 square feet of sawtimber basal area. The user must remember that the sawtimber stand is contained within the merchantable stand and avoid such illogical specifications.

Properly applied, these systems produce considerable detail on volume production, even though they are stand-level systems. They typically permit estimates of current and future merchantable cubic-foot volumes, sawtimber cubic-foot volumes, and board-foot volumes via one or more log rules. A future volume minus a current volume produces an estimate of growth. Pulpwood volume, current or future, can be obtained by subtracting a sawtimber cubic-foot volume from a corresponding merchantable cubic-foot volume, and growth is again estimated as the future pulpwood volume minus the current pulpwood volume.

## REFINEMENT ATTEMPTS

So, with this considerable amount of detail possible in our stand-level systems, what could be improved? The authors thought it possible to improve upon the estimates of stand board-foot volumes by the Doyle rule. Typically, board-foot fits of the Schumacher stand volume function are best for the International 1/4-inch rule, second best for the Scribner rule, and third best for the Doyle rule (table 2). But the Doyle rule, due to its common usage, is usually of the most interest. Relative to the other two rules, the Doyle rule underestimates the board-foot volumes of small trees, and the underestimates decrease as tree size increases. Therefore, it appeared that this disparity probably caused increased variability in Doyle volume observations and that it might be possible to improve the Doyle volume estimates via the Schumacher function by (a) adding new variables or (b) adding interactions of the basic three variables to account for more of the variation. However, attempts to do this were not successful.

Table 2.--Evaluation of Schumacher function fitted to sawtimber stand volumes by three log rules, natural loblolly pine

| Log rule | n | $\bar{y}$ | Criterion | | | | |
|---|---|---|---|---|---|---|---|
| | | | F.I. | $\bar{d}$ | RMSd | $\overline{\%d}$ | RMS%d |
| Doyle | 268 | 3707 | .86 | -25 | 1232 | 7 | 40 |
| Scribner | 268 | 5559 | .93 | -33 | 1173 | 2 | 25 |
| International 1/4-inch | 268 | 6547 | .94 | -37 | 1202 | 1 | 22 |

Typically, when one fits the Schumacher function to Doyle stand volume data, basal area accounts for the most variation, age is next most important, and site index is least important. For example, table 3 shows the results of adding variables to a model in the above sequence using 268 observations on Doyle stand volume in even-aged stands of natural loblolly pine. One can see that the sawtimber basal area (ln(BS)) accounted for about 72 percent of the variation; including age (1/A) added about 12 percent, and including site index (S) with age and sawtimber basal area added about 2 percent for a total of about 86 percent.

It seemed that information on merchantable basal area (BM) in addition to sawtimber basal area might improve the Doyle stand volume function fit. Therefore, the authors' first attempts to improve the Schumacher function were to add single variables such as ln(BM), ln(BM/BS), or ln(BM)/A to the model. These did improve the Fit Index a few percentage points and the resulting equations appeared logical when they were evaluated alone, but when they were inserted into software to evaluate thinning regimes, illogical results were obtained that were similar to those encountered in the Bennett (1970, 1980) slash pine system and the Farrar (1979) longleaf pine system -- at young ages an after-cut stand could have more predicted sawtimber volume than was predicted for the

Table 3.--Evaluation of constructing a Schumacher function for Doyle volume by sequentially including independent variables accounting for the most variation, natural loblolly pine

| Variable | n | $\bar{y}$ | Criterion | | | | |
|---|---|---|---|---|---|---|---|
| | | | F.I. | $\bar{d}$ | RMSd | $\overline{\%d}$ | RMS%d |
| ln(BS) | 268 | 3707 | .72 | 37 | 1744 | 24 | 57 |
| 1/A, ln(BS) | 268 | 3707 | .84 | -27 | 1320 | 7 | 40 |
| S, 1/A, ln(BS) | 268 | 3707 | .86 | -25 | 1232 | 7 | 40 |

before-cut stand, even though no sawtimber cut was simulated, because the BM was altered by the simulated cutting. Therefore, predictions can be similarly anomalous if any variable is included in a sawtimber stand volume function that can be altered in a simulated thinning, even though the sawtimber basal area is unaffected. Thus, it was apparent that any new variables would have to be restricted to some combination of site index, age, and sawtimber basal area if logical results in thinning applications were to be obtained.

Therefore, we next investigated the addition of possible interactions of S, 1/A, and ln(BS) to the Schumacher function. These possible interactions are S/A, (S)ln(BS), ln(BS)/A, and (S/A)ln(BS). Using the above loblolly data set, an "all possible combination" screening of regressions from the single-variable through the full seven-variable model was performed, and those equations having "goodness of fit" that showed any promise of improved predictions were evaluated. The "goodness of fit" criteria were Fit Index, mean deviation, mean percent deviation, root mean squared deviation, and root mean squared percent deviation, as defined in the footnotes to table 1. Some 60 regressions were evaluated alone and in a thinning simulation context, but we were not able to improve on the basic three-variable Schumacher function to predict Doyle stand volumes. Again, some regressions improved the Fit Index a few percentage points and otherwise showed improved fit, but when inserted into thinning simulation software these regressions either did not alter the predictions appreciably or, if they did, a new anomaly occurred -- the (Doyle/BS) ratio would decline at older ages rather than logically continue to increase.

## CONCLUSION

During the past quarter-century considerable progress has been made in stand-level modeling of volume and volume growth in thinned natural southern pine stands. Simultaneous-type stand-level volume and volume growth prediction systems are presently available for even-aged natural stands of the four major southern pines and for two uneven-aged pine types. These systems typically consist of one or two basal area drivers to project future basal areas and several stand volume functions that utilize basal area and other stand information to predict current and future volumes. They are also relatively simple, easy to implement on microcomputers, and valuable as a quick means to estimate expected volumes and growth for a wide variety of stand conditions, growth periods, thinning regimes, and rotation lengths. The amount of detail obtainable on volume and growth components is surprising. When inserted into relatively simple simulation software, these systems provide the capability of comparing a variety of "what if?" scenarios.

When utilizing the Schumacher stand volume function in such systems, it appears that once the main effects of stand basal area, age, and site index are accounted for, there would be little practical gain in trying to add other variables to improve the fit. This seems particularly true if logical results are to be expected in thinning simulations. There is still some debate over the long-term trends of the basal area development models, but they appear to be adequate for short periods or situations where repeated thinnings at short intervals are simulated. The associated stand-volume functions, in their present form, are probably essentially complete in their development, but the ultimate in this area of development has not necessarily been reached. Recent work by Amateis and others (1986) presents a stand-level volume-ratio model that portions total stand volume to any desired top diameter and/or threshold d.b.h. limit coupled with a model that distributes the total number of trees by d.b.h. class. If supplemented with a suitable survival function and basal area driver, this promises to afford an easily implemented stand volume and growth predictor that will allow product-volume detail comparable to that of d.b.h.-distribution predictors.

If detail on the size-class distribution of stems or volumes by product categories is desired, resorting to something similar or to diameter-distribution or individual-tree approaches in modeling is probably the best course. This is not to say that stand-level models similar to current forms will soon become extinct. Their aggregated estimates are entirely adequate for many purposes, and they will probably remain useful as compatible concomitants for diameter-distribution and individual-tree systems in which the user selects the set of predictors according to the detail desired.

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RECOVERING DIAMETER DISTRIBUTIONS FROM

SCHUMACHER AND COILE'S MODEL FOR

NATURAL EVEN-AGED LOBLOLLY PINE STANDS [1/]

Quang V. Cao [2/]

Abstract.--Schumacher and Coile's (1960) whole stand models for several southern pine species do not provide growth and yield information at the size-class level. This paper presents two methods of deriving a diameter distribution from Schumacher and Coile's model for even-aged natural stands of loblolly pine. Parameters of a Weibull function that described a diameter distribution were recovered such that either the resulting basal area (method 1) or volume per acre (method 2) was compatible with Schumacher and Coile's value.

Results indicated that it might not be possible to have complete compatibility for both volume and basal area. Method 1 provided compatible basal area estimates at the expense of consistently underestimating total volume per acre by 5 to 18 percent, as compared to Schumacher and Coile's model. On the other hand, method 2 overestimated basal area per acre by 5 to 19 percent in order to satisfy the volume constraint.

## INTRODUCTION

Whole stand models for natural stands of loblolly pine include those from Schumacher and Coile (1960), Brender and Clutter (1970), Burkhart et al. (1972), Sullivan and Clutter (1972), and Murphy (1983), to name a few. These models are used to predict yield for a stand in terms of volume per acre. Size-class information was recently provided by Burk and Burkhart (1984), who used the Weibull probability density function to approximate diameter distributions. Data employed in their study were previously used by Burkhart et al. (1972).

Forest managers who are currently using Schumacher and Coile's (1960) model for loblolly pine natural stands might need additional information on the distribution of trees and volume by size class. The objective of this study was to derive the parameters of a Weibull diameter distribution from Schumacher and Coile's model for even-aged natural stands of loblolly pine.

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## PROCEDURES

The Weibull probability density function used in describing diameter distributions has the following form:

$$f(x) = (c/b)\,[(x-a)/b]^{c-1} \exp\{-[(x-a)/b]^{c}\}, \qquad x > a,$$

where
x = diameter random variable,
a = location parameter,
b = scale parameter, and
c = shape parameter.

The location parameter (a) and the average stand diameter ($\bar{D}$) were predicted from regression equations developed by Burk and Burkhart (1984). Table 1 presents these two equations along with Schumacher and Coile's (1960) equations for yield prediction. The other Weibull parameters (b and c) were obtained (or recovered) using the following methods.

### Method 1

The average diameter and basal area per acre, computed from the Weibull diameter distribution, were constrained to be identical to those from regression equations. This method involved solving for the Weibull parameters b and c from the following system of equations:

Table 1.--Equations from Burk and Burkhart (1984) and Schumacher and Coile (1960) that form a whole stand model for natural stands of loblolly pine.

| Equation Number | Variable | Equation [a] |
|---|---|---|
| | | Burk and Burkhart (1984) |
| 1 | Weibull location parameter | $a = \text{maximum}\ (0.0,\ -3.6732 + 0.01111\ B + 0.6876\ Dq)$ |
| 2 | Arithmetic mean diameter | $\ln(Dq - \bar{D}) = 32.9856 - 4.7745 \ln(H) - 326.1481/H - 1.7136 \ln(B) - 109.5631/B$ |
| | | Schumacher and Coile (1960) |
| 3 | Individual tree volume | $V_i = 0.0817\ D_i + (H/100)\ (0.4237 - 0.64042\ D_i + 0.227872\ D_i^2)$ |
| 4 | Dominant height | $\log(H) = \log(SI) - 6.528\ (1/A - 1/50)$ |
| 5 | Stocking percent | $SP = B\ [0.8409 - 0.001707\ H + 10.62/A - 0.1408\ (H/A)]$ |
| 6 | Trees per acre | $\log(N) = 4.1218 + 2.6843/A - 1.7130 \log(H) + 0.6343 \log(B)$ |
| 7 | Average volume per tree | $\log(V/N) = -3.3920 + 1.3321 \log(Dq) + 1.7411 \log(H)$ |

[a] Notation

- $a$ = Weibull location parameter,
- $A$ = Stand age in years,
- $B$ = Basal area in sq. ft./acre,
- $Dq$ = Quadratic mean diameter in inches,
- $\bar{D}$ = Average diameter, or arithmetic mean dbh, in inches,
- $H$ = Average height in feet of the dominants and codominants,
- $D_i$ = Diameter at breast height in inches of tree i,
- $V_i$ = Total cubic-foot volume inside bark of tree i,
- $V$ = Total cubic-foot volume inside bark per acre,
- $SI$ = Site index in feet, base age 50 years,
- $SP$ = Stocking percent,
- $N$ = Trees per acre.

$$\bar{D} = \int_a^\infty x\, f(x)\, dx$$

and
$$B = KN \int_a^\infty x^2\, f(x)\, dx$$

or, in another form:

$$\bar{D} = a + b\Gamma(1 + 1/c)$$

and
$$B = KN\, [a^2 + 2a\, \bar{D} + b^2\Gamma(1 + 2/c)]$$

where $\Gamma(.)$ = the complete gamma function,
$K$ = 0.005454 if diameter is in inches and basal area in square feet,
$N$ = number of trees per acre.

After all Weibull parameters had been obtained, a stand and stock table was generated and the resulting total volume per acre was evaluated against Schumacher and Coile's yield value.

Method 2

In this approach, the Weibull parameters b and c were recovered such that the diameter distribution yielded the same values for average stand diameter and total volume per acre as did those predicted from regression equations. In other words, b and c are solutions of

$$\bar{D} = \int_a^\infty x\, f(x)\, dx$$

and
$$V = N \int_a^\infty v(x)\, f(x)\, dx$$

or, in another form:

$$\bar{D} = a + b\Gamma(1 + 1/c)$$

$$V/N = b_1\bar{D} + (H/100)\, [b_2 + b_3\bar{D} + b_4(a^2 + 2a\bar{D} + b^2\Gamma(1 + 2/c))]$$

where $H$ = average height in feet of the dominants and codominants,
$V$ = total cubic-foot volume inside bark per acre,
$b_i$ = coefficients from equation (3) of Table 1:
$b_1$ = 0.0817; $b_3$ = -0.64042;
$b_2$ = 0.4237; $b_4$ = 0.227872.

This approach ensured that total volume per acre computed from the diameter distribution was compatible with Schumacher and Coile's predicted value. The percent difference between Schumacher and Coile's basal area and the Weibull-generated basal area per acre was then calculated.

## RESULTS AND DISCUSSION

The evaluation of method 1 is shown in Table 2, which presents total volume per acre values predicted from Schumacher and Coile's whole stand model and those computed from the Weibull diameter distribution, for combinations of site index, age, and basal area per acre. Stand densities used in these combinations were predicted from equation (5) of Table 1 for "well-stocked" loblolly pine stands. Per acre volumes from the Weibull distribution were consistently lower by 5 to 18 percent than their counterparts predicted from the regression equation for a given basal area level.

The information in Table 3 shows a similar trend in basal area for method 2. For a specified level of total volume per acre, the Weibull distribution resulted in an increase of 5 to 19 percent in basal area value. As an example, the Weibull distributions derived from both methods are presented in Figure 1 for a well-stocked stand of site index 70 feet (base age 50) at age 40.

These results explained the failure of an initial attempt by the author to derive a Weibull diameter distribution such that both basal area and volume per acre were compatible with Schumacher and Coile's predicted values. Either convergence problems were encountered or an illogical diameter distribution (reverse J-shape curve with a heavy right tail) resulted from this attempt. Frazier (1981) also reported convergence problems in his similar efforts with both the Weibull and beta distributions for loblolly pine plantations.

If a forester chooses to use Schumacher and Coile's (1960) whole stand model and desires additional information at the size-class distribution level, he has to decide between using method 1 for compatible basal area per acre or method 2 for compatible volume per acre. Method 2 is useful for partitioning stand volume into different product volumes.

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Table 2.--Evaluation of volumes from Schumacher and Coile's (1960) regression equation and from the Weibull diameter distribution (method 1) for various combinations of site index (base age 50), age, and basal area per acre.

| Site index | Age | Basal area | V a/ | $\tilde{V}$ b/ | Diff.c/ |
|---|---|---|---|---|---|
| ft | yrs | $ft^2/ac$ | $ft^3/ac$ | $ft^3/ac$ | % |
| 70 | 20 | 102 | 1689 | 1390 | 17.70 |
| | 40 | 130 | 3091 | 2787 | 9.83 |
| | 60 | 139 | 3720 | 3451 | 7.24 |
| | 80 | 142 | 4055 | 3810 | 6.05 |
| 90 | 20 | 115 | 2518 | 2087 | 17.12 |
| | 40 | 149 | 4669 | 4253 | 8.90 |
| | 60 | 158 | 5574 | 5214 | 6.47 |
| | 80 | 160 | 6029 | 5691 | 5.61 |
| 110 | 20 | 132 | 3591 | 3017 | 15.97 |
| | 40 | 175 | 6771 | 6271 | 7.39 |
| | 60 | 182 | 8000 | 7563 | 5.47 |
| | 80 | 183 | 8566 | 8159 | 4.75 |

a/ V = Total volume ib (cu.ft./acre) from Schumacher and Coile (1960),

b/ $\tilde{V}$ = Total volume ib (cu.ft./acre) from the Weibull diameter distribution,

c/ Difference % = 100 $(V - \tilde{V})/V$.

Table 3.--Evaluation of stand basal areas from Schumacher and Coile's (1960) regression equation and from the Weibull diameter distribution (method 2) for various combinations of site index, age, and volume per acre.

| Site index | Age | Total ib volume | B a/ | $\tilde{B}$ b/ | Diff.c/ |
|---|---|---|---|---|---|
| ft | yrs | $ft^3/ac$ | $ft^2/ac$ | $ft^2/ac$ | % |
| 70 | 20 | 1689 | 102 | 121 | -18.85 |
| | 40 | 3091 | 130 | 143 | -9.43 |
| | 60 | 3720 | 139 | 148 | -6.71 |
| | 80 | 4055 | 142 | 150 | -5.62 |
| 90 | 20 | 2518 | 115 | 136 | -18.10 |
| | 40 | 4669 | 149 | 162 | -8.52 |
| | 60 | 5574 | 158 | 167 | -6.18 |
| | 80 | 6029 | 160 | 168 | -5.11 |
| 110 | 20 | 3591 | 132 | 154 | -16.65 |
| | 40 | 6771 | 175 | 187 | -7.23 |
| | 60 | 8000 | 182 | 192 | -5.18 |
| | 80 | 8566 | 183 | 191 | -4.55 |

a/ B = Basal area (sq.ft./acre) from Schumacher and Coile (1960),

b/ $\tilde{B}$ = Basal area (sq.ft./acre) from the Weibull diameter distribution,

c/ Difference % = 100 $(B - \tilde{B})/B$.

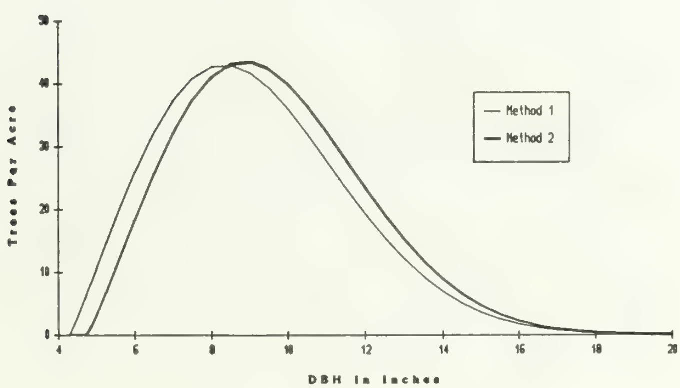


Figure 1.--Weibull distributions derived from both methods for a stand of site index 70 at age 40.

THE PREDICTION OF DATA INTO MULTIPLE CATEGORIES USING A FORM OF LOGISTIC REGRESSION[1/]

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Abstract.--A considerable amount of data in forestry is grouped into distinct classes, ie. dbh classes, crown classes, stocking levels, and product classes. A form of logistic regression can be used to predict such multiple classifications. This technique will be valuable in making predictions for many variables used in forestry. Examples are presented of predictions made into some of the common classifications used in forestry.

## INTRODUCTION

Much of the data collected in forestry is done by placing observations into discrete classes. Some common examples of variables collected by a classification system are: crown class, tree class, log grade, and site class. In some cases, such classifications are the only way information may be obtained on the variable. Furthermore, such forms of categorization can provide a forester with a wealth of information, and the prediction of observations into such classes can be quite useful. However, standard linear regression techniques do not provide an adequate framework for modeling such class variables.

The logistic function has been applied frequently in forestry to model the probability of mortality (Hamilton 1974, Monserud 1976). This function may also be used to predict the probabilities of an event occurring in several categories. This technique has been successfully used in the medical field, and is well documented in the statistical literature (Anderson 1982, Vitalino 1978, Walker and Duncan 1967). Furthermore, routines exist in most major statistical packages (SAS, BMDP) to fit models using the logistic function.

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## LOGISTIC FUNCTION

The logistic function is most easily understood by first examining the case for predicting only 2 classes (0,1), or what is commonly referred to as a dichotomous dependent variable (Walker and Duncan 1967). If we define:

$P_0$ = probability of 0 occurring;

$P_1$ = probability of 1 occurring;

probability theory then tells us:

$$P_0 = 1.0 - P_1.$$

Therefore, by knowing $P_1$ we also know $P_0$. In turn only one of these probabilities needs to be modeled, say $P_1$ for this example. Using the logistic function the model for $P_1$ can be defined to be;

$$P_1 = \frac{1.0}{1.0 + e^{(-\alpha - \boldsymbol{\beta} \mathbf{X})}}$$

where,

$\alpha$, $\boldsymbol{\beta}$ - parameters to be estimated.

$\mathbf{X}$ - predictor variables.

In deriving this logistic regression equation, only one assumption is required, namely that the natural log (ln) $(P_0/P_1)$ is linearly related to the predictor variables, $\mathbf{X}$. As no requirements

are made on the distribution of **X**, they may be either discrete or continuous (Affi and Clark 1984). However the estimates of $\alpha$ and $\beta$ are usually made through maximum likelihood methods, thereby requiring ample observations in each class to arrive at an accurate estimation. This use of the logistic regression equation has commonly been used in forestry to predict mortality. It may also be used to predict such variables as merchantability, disease and/or insect infestations, and the probability of fire.

Many variables in forestry are collected by a classification system having more than simply two levels. Therefore, this simple case of predicting a dichotomous variable can not always be utilized. If the variable is collected in ordered categories, logistic regression can be used for their prediction. To explain how such predictions are made the case where the response variable takes on three ordered values (1,2,3) is examined. In this case we will define;

$P_1$ = probability of 1 occurring;

$P_2$ = probability of 2 occurring;

$P_3$ = probability of 3 occurring.

Then from probability theory we know that;

$$P_1 = 1.0 - (P_2 + P_3).$$

So that by knowing the quantity $(P_2 + P_3)$ we also know $P_1$. As in the dichotomous case, the logistic function is used to define the model for $(P_2 + P_3)$ to be;

$$P_2 + P_3 = \frac{1.0}{1.0 + e^{(-\alpha_1 - \beta X)}}$$

where:

$\alpha_1$, $\beta$ - parameters to be estimated

**X** - predictor variables.

Next, the probability of being in class 1, $P_1$, is ignored, and the probability of being in class 2 or class 3 is calculated. For these two probabilities it is known that;

$$P_2 = (P_2 + P_3) - P_3.$$

Since a model has been constructed for $(P_2 + P_3)$, only $P_3$ needs to be determined to get $P_2$.

Once again, using the logistic function the model for $P_3$ is defined to be:

$$P_3 = \frac{1.0}{1.0 + e^{(-\alpha_2 - \beta X)}}$$

where:

$\alpha_2$, $\beta$ - parameters to be estimated

**X** - predictor variables.

This logistic regression equation is also related to the equation for the quantity $(P_2 + P_3)$. It is even assumed that the slope parameters $\beta$ are the same in the two models. Once the two models have been fit, $P_1$ and $P_2$ are then simply calculated by subtraction.

At this point the probabilities $P_1$, $P_2$ and $P_3$ can be estimated for any individual. A simple assignment scheme, such as selecting the class with the greatest probability and assigning that to be the prediction of the response variable, can be used. Of course, all the previous restrictions for the dichotomous dependent variable are applicable to this situation. Applications requiring further classes would simply be extensions of this case.

## DATA AND METHODS

To illustrate the use of logistic regression, examples of predictions for log grade, tree class, and crown class are presented. The data used in these predictions are for shortleaf pine (Pinus echinata Mill) from Continuous Forest Inventory (CFI) plots in even aged stands in the Piedmont region of Alabama. Predictor variables available for this analysis consisted of tree variables, such as dbh, total height, and sawlog height, and plot variables such as basal area/acre, trees/acre, and site index.

Calculations were made using the Proc Logist routine in the SAS User Supplemental Library (Harrell 1986). Variable selection was done by plotting the variables and by using a stepwise option available in Proc Logist. This selection was then augmented by subjective decisions based on considerations such as ease of measurement and/or faith in the meaningfulness of the variable. Once variables were selected, Proc Logist was again used to estimate the regression coefficients, $\alpha$ and $\beta$.

To determine how well the resultant logistic equation fits the data, Proc Logist computes several different but related fit statistics. The first two statistics are called Model Chi-Squares. They are calculated using the estimated model parameters, $\alpha$ and $\beta$, and are

approximately distributed as chi-square variables. These Chi-Squares values test the joint significance of all the variables in the equation (Harrell 1986). A large Model Chi-Square value, with a corresponding low probability or P value, is an indication that the variables are useful in the model (Affi and Clark 1984). The first Model Chi-Square calculated by Proc Logist is labeled the Score Statistic. This value is calculated before $\alpha$ and $\beta$ are estimated, and is only useful if the parameter estimates do not converge. If the parameters do converge then a Model Likelihood Ratio (L.R.) Chi-Square is calculated and labeled the -2 Log L.R. Chi-Square. This is also commonly known in the statistical literature as the $G^2$ statistic. Each Model Chi-Square is also output with its corresponding approximate P value and a statistic called R. This R statistic is similar to the multiple correlation coefficient, R-Square, in linear regression analysis. An R statistic of 0 would indicate a poor fit and a value of 1 would indicate a perfect relationship. These statistics are very useful in determining the overall fit of the model.

Next Proc Logist outputs statistics on the intercepts and variables in the model. In each case, the coefficient, its standard error, a chi-square value, and it's associated P value are output. Then for each variable in the model, an individual R statistic is calculated. These R statistics measure the contribution of that variable to the model. An R value of 0 will indicate that the variable provides no contribution to the model, an R value of 1 indicates that the variable is perfectly related in the positive direction, and an R value of -1 indicates that the variable is perfectly related in the negative direction (Harrell 1986). These individual statistics are particularly helpful in the selection of variables to be included in the model.

Lastly, four statistics are output which assess the predictive ability of the entire model. These four statistics are the C, Somer Dyx, Gamma, and tau-a. All of these statistics attempt to rank the correlation between the predicted probabilities and the observed outcomes. In all cases, a value of 0 would indicate a poor fit and a value of 1 would indicate a perfect fit. For more information on how these values are calculated, please refer to Harrell (1986) and/or Goodman and Kruskal (1979). All of these statistics may be viewed when assessing the model. However, when the model contains discrete dependent variables the C or Somer Dyx are usually the most meaningful. Similarly, if it is desired to compare a model which contains mainly continuous variables to a model with discrete variables, then tau-a would be preferred. Although the Gamma statistic is output its use is not highly recommended.

## EXAMPLE 1. LOG GRADES

Log grade is one of the more common and valuable variables collected by means of a classification system. The data presented 3 classes of log grade:

| Log Grade | Clear Faces[3/] |
|---|---|
| 1 | 3-4 |
| 2 | 1-2 |
| 3 | 0 |

Furthermore, due to the definition of log grade, only trees with diameters greater than the 8-inch dbh class were considered. Variables selected to model log grade were dbh, site index, and sawlog height. Table 1 presents the results from Proc Logist. The Model Chi-Square indicates that the model was significant. The individual Chi-Squares also show a good fit. However, the individual R statistics do not indicate a very good fit and the values for the C and Somer Dyx only indicate a moderately well fit model. Next, a frequency table of actual log grade versus predicted log grade is presented in Table 2. This table reveals that 71% of the time the predicted values were the same as the actual value, and that 98% of the time the predictions agreed with or were within 1 grade of the actual log grade.

## EXAMPLE 2. CROWN CLASSES

Crown classes are frequently collected to describe a stand. In the example data set, five crown classes existed:

0 - Dominant
1 - Co-dominant
2 - Intermediate
3 - Suppressed
4 - Open Grown

Due to a lack of observations in crown class 4 and because open grown trees in a typical stand were viewed as occurring very rarely, class 4 was dropped from this analysis. The variables selected to model crown class were basal area bigger[4/], dbh, and site index. Table 3 shows the regression coefficients and associated statistics from Proc Logist. As with the log grade model, the crown class model was significant, but only a moderate fit was obtained. Table 4 is the

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3/ Clear faces are those free of knots measuring more than a half inch in diameter, overgrown knots of any size, or holes of more than a quarter of inch in diameter.

4/ Basal area bigger is defined as the amount of basal area/acre of trees greater than or equal to the basal area of the current tree.

Table 1.--Results of the Prediction of Log Grade, using Proc Logist.

144 Observations
13 Log Grade = 1
40 Log Grade = 2
91 Log Grade = 3
0 Observations deleted due to missing values

| Variable | Mean | Minimum | Maximum | Std. Dev. |
|---|---|---|---|---|
| Site Index | 79.9306 | 60 | 100 | 10.2757 |
| Dbh | 11.6653 | 8.6 | 20.6 | 2.64192 |
| Saw Log Height | 37.9861 | 12 | 76 | 15.1602 |

-2 LOG LIKELIHOOD FOR MODEL CONTAINING INTERCEPTS ONLY = 248.53

MODEL CHI-SQUARE = 66.06 WITH 3 D.F. (SCORE STAT.) P = 0.0
CONVERGENCE IN 6 ITERATIONS WITH 0 STEP HALVINGS R = 0.503
MAX ABSOLUTE DERIVATIVE = 0.1029D-06. -2 LOG L = 179.62
MODEL CHI-SQUARE = 68.91 WITH 3 D.F. (-2 LOG L.R.) P = 0.0

| Variable | Beta | Std. Error | Chi-Square | P | R |
|---|---|---|---|---|---|
| Alpha1 | 4.94349250 | 1.87303953 | 6.97 | 0.0083 | |
| Alpha2 | 2.24502530 | 1.78911764 | 1.57 | 0.2095 | |
| Site | 0.05810954 | 0.02106371 | 7.61 | 0.0058 | 0.150 |
| Dbh | -0.33812881 | 0.11144510 | 9.21 | 0.0024 | -0.170 |
| Saw Log Height | -0.05748074 | 0.02102516 | 7.47 | 0.0063 | -0.148 |

C = 0.844 Somer Dyx = 0.688 Gamma = 0.692 tau-a = 0.35

Table 2.--Frequency Table of Actual Log Grade verus Predicted Log Grade

| Actual Log Grade / Frequency | Predicted Log Grade 1 | 2 | 3 | Total |
|---|---|---|---|---|
| 1 | 4 | 6 | 3 | 13 |
| 2 | 4 | 17 | 19 | 40 |
| 3 | 0 | 9 | 82 | 91 |
| Total | 8 | 32 | 104 | 144 |

Table 3.--The Predicition of Crown Class, using Proc Logist

342 Observations
129 Crown Class = 0
95 Crown Class = 1
72 Crown Class = 2
46 Crown Class = 3
0 Observations deleted due to missing values

| Variable | Mean | Minimum | Maximum | Std. Dev. |
|---|---|---|---|---|
| Basal Area Bigger | 56.6959 | 10 | 200 | 36.2771 |
| Dbh | 8.37134 | 1.4 | 20.6 | 3.56795 |
| Site Index | 78.1287 | 50 | 100 | 11.0984 |

-2 LOG LIKELIHOOD FOR MODEL CONTAINING INTERCEPTS ONLY = 903.87

MODEL CHI-SQUARE= 207.16 WITH 3 D.F. (SCORE STAT.) P = 0.0
CONVERGENCE IN 6 ITERATIONS WITH 0 STEP HALVINGS R = 0.485
MAX ABSOLUTE DERIVATIVE = 0.4418D-08. -2 LOG L = 685.41
MODEL CHI-SQUARE = 218.45 WITH 3 D.F. (-2 LOG L.R.) P = 0.0

| Variable | Beta | Std. Error | Chi-Square | P | R |
|---|---|---|---|---|---|
| Alpha1 | 0.33336046 | 0.78198519 | 0.18 | 0.6699 | |
| Alpha2 | -1.54389519 | 0.78421665 | 3.88 | 0.0490 | |
| Alpha3 | -3.43248757 | 0.80670645 | 18.10 | 0.0000 | |
| Basal Area Bigger | 0.02308911 | 0.00391802 | 34.73 | 0.0000 | 0.190 |
| Dbh | -0.37443864 | 0.04776247 | 61.46 | 0.0000 | -0.256 |
| Site Index | 0.02988253 | 0.01055918 | 8.01 | 0.0047 | 0.082 |

C = 0.827 Somer Dyx = 0.655 Gamma = 0.656 tau-a = 0.47

Table 4.--Frequency Table of Actual Crown Class verus Predicted Crown Class

Predicted Crown Class

| Actual Crown Class / FREQUENCY | 0 | 1 | 2 | 3 | Total |
|---|---|---|---|---|---|
| 0 | 99 | 26 | 4 | 0 | 129 |
| 1 | 40 | 35 | 18 | 2 | 95 |
| 2 | 10 | 16 | 37 | 9 | 72 |
| 3 | 0 | 8 | 19 | 19 | 46 |
| Total | 149 | 85 | 78 | 30 | 342 |

frequency table of actual crown class versus predicted crown class. With this model, predictions agreed with actual observations in 56% of the cases and were within 1 class 93% of the time. However, it is noteworthy that predictions were correct 77 % of class 0 (dominants), 37 % of class 1 (co-dominants), 51 % of class 2 (intermediates), and 41% of class 3 (suppressed).

### EXAMPLE 3. TREE CLASSES

Tree class is another common variable collected in CFI data. In these data, tree classes were represented by :

0 - Desirable Tree
1 - Acceptable Tree
2 - Undesirable Tree
3 - Cull Tree

Very few observations existed in category 3. Therefore, to avoid problems of convergence to the maximum likelihood estimate, categories 2 and 3 were combined. Variables selected to model tree class were total height, crown class, and· dbh. Table 5 shows the results from Proc Logist. Once again, the model was only a moderate fit. Table 6 displays a frequency table of actual tree class versus predicted tree class. With this model, predictions agreed with actual tree classes 65% of the time, and were within 1 class 99% of the

## CONCLUSIONS

This paper has presented the theory and methodology by which multiple classifications may be predicted. Examples of predictions for log grade, tree class, and crown class were given. The results from these predictions, though not always perfect were acceptable. Also, the examples were for categories which are highly subjective in their measurements. Therefore any prediction will be imperfect. Furthermore, when the alternative is to not divide predictions into classes, logistic regression is very desirable.

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Table 5.--Results of the Prediction of Tree Class, using Proc Logist.

344 Observations
102 Tree Class = 0
156 Tree Class = 1
86 Tree Class = 2
0 Observations deleted due to missing values

| Variable | Mean | Minimum | Maximum | Std. Dev. |
|---|---|---|---|---|
| Crown Class | 3.09012 | 1 | 5 | 1.0666 |
| Total Height | 52.5698 | 15 | 102 | 17.514 |
| Dbh | 8.3686 | 1.4 | 20.6 | 3.56067 |

```
-2 LOG LIKELIHOOD FOR MODEL CONTAINING INTERCEPTS ONLY = 733.16

MODEL CHI-SQUARE = 181.59 WITH 3 D.F.          (SCORE STAT.) P = 0.0
CONVERGENCE IN 6 ITERATIONS WITH 0 STEP HALVINGS             R = 0.501
MAX ABSOLUTE DERIVATIVE = 0.2973D-07.                   -2 LOG L = 543.40
MODEL CHI-SQUARE = 189.76 WITH 3 D.F.         (-2 LOG L.R.) P = 0.0
```

| Variable | Beta | Std. Error | Chi-Square | P | R |
|---|---|---|---|---|---|
| Alpha1 | 0.84292520 | 0.67989908 | 1.54 | 0.2151 | |
| Alpha2 | -2.22047247 | 0.70662535 | 9.87 | 0.0017 | |
| Crown Class | 1.01485148 | 0.14398809 | 49.68 | 0.0000 | 0.255 |
| Total Height | -0.03106537 | 0.01271129 | 5.97 | 0.0145 | -0.074 |
| Dbh | -0.11394357 | 0.06938842 | 2.70 | 0.1006 | -0.031 |

C = 0.826 Somer Dyx = 0.652 Gamma = 0.654 tau-a = 0.42

Table 6.--Frequency Table of Actual Tree Class verus Predicted Tree Class

| Actual Tree Class / FREQUENCY | Predicted Tree Class 0 | 1 | 2 | Total |
|---|---|---|---|---|
| 0 | 59 | 41 | 2 | 102 |
| 1 | 31 | 106 | 19 | 156 |
| 2 | 1 | 28 | 57 | 86 |
| Total | 91 | 175 | 78 | 344 |

# Preserving and Maintaining

# Permanent Growth & Yield Research Plots[1]

J. David Lenhart[2]

Abstract.--In a comprehensive long-term plantation research project, a relatively large proportion of a carefully installed set of permanent plots have been lost or destroyed within the initial five years due to acts of nature or man. As a result, the program to protect, preserve and maintain existing plots plus re-establish lost plots has intensified.

When we installed a comprehensive set of permanent plots throughout East Texas on industrial forest lands during 1982, 1983 and 1984 to provide data to drive the East Texas Pine Plantation Research Project for the next 20-30 years, we accepted the fact that occasionally a plot will be lost due to reasons beyond our control. And when a plot is ruined or destroyed, we would re-establish the plot as soon as possible. In this manner, the tracking of plantation development is quickly re-started.

## PLOT UTILIZATION

A total of 256 plots--178 in loblolly (*Pinus taeda* L.) and 78 in slash pine (*Pinus elliottii* Engelm.) plantations--were initially installed throughout East Texas by SFASU, School of Forestry personnel (Lenhart et al. 1985). Each rectangularly shaped plot is 1.2 acres in size. We are monitoring the growth and development of the planted pines plus sampling and measuring other environmental factors, which may be affecting the production of wood by the pine trees. Plot remeasurement is on a 3-year cycle, and the ETPPRP is expected to terminate in 2012. Numerous graduate students, faculty members and industry personnel are currently studying and analyzing the plantation values and, thus, are dependent on the ETPPRP plots as a primary data source.

## INITIAL PRESERVATION AND MAINTENANCE PLAN

The participating landowners and the School of Forestry recognized the importance of maintaining and preserving a set of permanent plots. Our initial plan to try and insure that each plot survived until its final harvest, which may be 10-30 years in the future, consisted of:

1. Remeasuring plots on 3-4 year cycle.
2. Informing company personnel of plot locations.
3. Marking the research plots on all company maps.
4. Encouraging companies to avoid potentially adverse activities around the plots.

There are approximately two million acres of pine plantations on industrial forest land in East Texas. Our 256 plots represent a sample of 307 acres or 0.015 percent of the total planted acreage. We felt that the completely random probability of an individual damaging activity occurring within any of the 256 plots, much less on a single plot, was extremely small. We were confident that a very large proportion of our sample should be spared from destructive forces, even during a long-range project such as the ETPPRP.

## PLOT DESTRUCTION

After the initial five years of operating the ETPPRP, an interesting and unexpected set of reasons has caused a relatively large loss of 27 of the 256 permanent plots, Table 1.

[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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Table 1. Summary of ETPPRP plots destroyed 1982-86.

| Reason | Number |
|---|---|
| Land sale | 6 |
| Southern Pine Beetle | 3 |
| Incorrect plot location | 3 |
| Rabbits/Ants | 2 |
| Vandalized | 2 |
| Prescribed fire | 2 |
| Oil/gas well construction | 2 |
| Replanted | 2 |
| Rifle range construction | 1 |
| Deer stand construction | 1 |
| Road construction | 1 |
| Wildfire | 1 |
| Choked by tag wires | 1 |
| | 27 |

To our surprise, ownership changes of the land where plots are located are the primary reason for loss of research plots. Owens-Illinois, Inc., one of the five original participating companies, sold some of their land to a developer. That developer is now the proud owner of six research plots.

Of the 27 destroyed plots, only 5 were lost due to acts of nature-rabbits and SPB-and basically could not be controlled by man. The 22 remaining plots were destroyed by the actions of man. In some instances, perhaps, either ETPPRP personnel or company personnel could have prevented plot destruction. However, the rifle range and deer stand were constructed on hunting leases without permission and contrary to lease regulations. In the case of oil/gas well construction, company personnel, as usual, had no control over where the well pads were located. By the way, both holes were dry.

## REVISED PRESERVATION AND MAINTENANCE PLAN

In the initial five years of this approximately 30-year long project, we have lost 27 of our original 256 plots (11 percent or 1 in 9) or about 5-6 plots per year on the average. We have been able to re-establish 10 of the 27 plots, so at this point, our net loss is 17 plots. For the remaining years of the ETPPRP, we will intensify our original plot survival procedures. In addition, we have decided to:

1. Remeasure plots on a 3-year cycle.
2. Keep field personnel informed of plot locations.
3. Paint a bright line around all 960 feet of buffer zone perimeter.
4. Post research area signs along the buffer zone perimeter.
5. Flag the perimeter of each of the two subplots within a plot.

We hope that by making the research plots very visible, inadvertent intrusion and destruction will be minimized.

We have also realized that in order to prevent our research plots from slowly dwindling away, we must be more active in plot re-establishment than we had originally thought.

## ACKNOWLEDGMENT

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# Incorporating Precipitation into a Basal Area Growth Model[1/]

Paul A. Murphy and Robert M. Farrar, Jr.[2/]

Abstract.--The Chapman-Richards function was selected as the model for basal area development of uneven-aged loblolly-shortleaf pine stands. This function uses initial basal area and elapsed time as independent variables; it was modified to include various measures of growing season rainfall. July-September rainfall increased the predictive power of the basal area equation and was superior to other rainfall variables. The equations using the other rainfall variables were not better than the basic model. Though gains were not as great as anticipated, use of growing season rainfall as a variable in growth and yield models merits further study.

Keywords: Mathematical models, growth and yield, rainfall.

## INTRODUCTION

It has long been recognized that tree growth is greatly affected by the amount and timing of precipitation. Indeed, pioneering work by Coile (1936) on the effect of rainfall and temperature cites still earlier experimental work on the southern pines by Lodewick (1930).

At the start of the growing season, the soil is usually at field capacity, having been recharged during the winter months of higher rainfall and lower evapotranspiration. As the growing season progresses and temperatures increase, evapotranspiration demands become larger and rainfall may decrease, which puts demands on the water supply in the soil. If potential evapotranspiration exceeds actual transpiration, a moisture deficit occurs. This situation is ameliorated late in the growing season when evapotranspiration demands lessen. Summer droughts exacerbate these soil-moisture deficits.

It was the common occurrence of summer droughts in the West Gulf Coastal Plain that spurred research on growing season soil-moisture deficiencies at the Crossett Experimental Forest in the 1950's and 1960's. Moyle and Zahner (1954) and Zahner (1955) found that undisturbed forests of different species compositions on similar soils had essentially the same summer soil-moisture depletion, which substantiated the supposition that potential evapotranspiration is independent of vegetative cover. Zahner (1958), in contrast to undisturbed stands, found that understory hardwood removal increased the soil moisture available to the loblolly and shortleaf pine (Pinus taeda L., P. echinata Mill.) overstory. Bassett (1964a) found that when even-aged loblolly-shortleaf pine stands were periodically thinned, those thinned to higher densities experienced declines soil moisture and less diameter growth than stands thinned to a low density. Sometimes the stands thinned to the low density did not even experience a lessening in diameter growth because available soil moisture was not depleted.

Bassett (1964b) quantitatively investigated the relationship between soil moisture availability and basal-area and cubic-foot volume growth of an uneven-aged loblolly-shortleaf pine stand by linear regression. His independent variables, growth days and growth-day index, are too complicated to use on an operational basis, but his work shows that soil moisture or related variables can be used in growth and yield projection equations. Zahner and Stage (1966) proposed a method for calculating daily moisture stress that can be used in diameter growth equations. In a more recent work, Shoulders and Tiarks (1980) developed prediction equations for the total height of 20-year-old plantation trees of the major southern pines using rainfall, slope, and available soil moisture as variables.

[1/]Paper presented at Fourth Biennial Southern Silvicultural Research Conference, Atlanta, GA, November 4-6, 1986.

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Beck (1985) has also used a growing season precipitation variable to model the annual diameter growth of yellow-poplar (Liriodendron tulipfera L.). Chang and Aguilar (1980) investigated the effects of climate and soil on the radial growth of loblolly pine.

These studies and many others reviewed by Zahner (1968) have conclusively demonstrated that precipitation and soil moisture can each affect tree growth. The studies cited here have either evaluated how soil moisture and rainfall have affected seasonal growth or have used elaborate indices based on daily measures of soil moisture and other variables to evaluate periodic growth of several years. There has not been an analysis that has attempted to relate periodic diameter or basal area growth of several years to cumulative rainfall of the same period.

Most growth and yield studies have used variables such as stand density, site index, stand age, or length of the growth period to forecast stand growth and development. Long-term growth studies are now being used to assess the impact of atmospheric deposition, and it is important to eliminate climatic effects before evaluating pollution impacts. Otherwise, atmospheric deposition or other factor may be improperly identified as the causal agent when it actually may be climate.

Rainfall records are easily available, and precipitation data have been collected intensively for many years. Since soil moisture is a prime factor of tree and stand growth, and rainfall is highly correlated with soil moisture, rainfall can act as a surrogate variable. Thus, growing season rainfall is a primary climatic variable to include in growth and yield equations.

We decided to examine the feasibility of incorporating precipitation into a basal area projection model for uneven-aged loblolly-shortleaf pine stands in southern Arkansas. We wanted to determine if periodic rainfall could be related to periodic basal area growth. The term "periodic" is used to imply an interval of several years.

## DATA

The data we used are from the cutting cycle study (Reynolds 1959, 1969), the methods-of-cutting study ( Baker and Murphy 1982, Grano 1954), and unpublished research conducted at the Crossett Experimental Forest and adjacent areas in south Arkansas in uneven-aged loblolly-shortleaf pine stands. An uneven-aged loblolly-shortleaf pine growth and yield model has also been developed using these data (Farrar and others 1984; Murphy and Farrar 1982, 1983).

The predominant soil in these stands is Bude silt loam, which is a member of the fine-silty, mixed thermic family of Glossaquic Fragiudalfs. The site index for loblolly pine is 80 to 90 feet at base age 50 (U.S. Department of Agriculture, Forest Service 1976).

Stand growth information was obtained from periodic 100-percent cruises of plots and compartments that ranged from 2.5 to more than 40 acres in size. Records were kept of stand inventories, harvest cuts, salvage cuts, and thinnings by 1-inch classes for loblolly and shortleaf pine trees 3.6 inches in d.b.h. and larger. Remeasurement intervals varied from 3 to 9 years. Collection of most of these data started in 1937 and continued into the late 1960's.

All species were tallied in the methods-of-cutting study, and all were initially inventoried in the cutting cycle study by 10-acre subcompartments. In 1948, all hardwoods on the cutting cycle study were controlled by injecting or girdling, and thereafter tallies were kept only for pine by 40-acre compartments.

Basal areas per acre were calculated for shortleaf and loblolly pine trees 3.6 inches and larger in d.b.h. If a harvest occurred within half a growing season of the initial inventory, its basal area was deducted from the initial value; otherwise harvest basal areas were added to the ending basal area. The difference between initial and final values provides an observation on net change resulting from survivor growth, ingrowth, mortality, and growth on harvested trees. Any observations showing a negative change (indicating excessive mortality) were deleted from the analysis. Most compartments were measured several times and yielded several growth observations. The final number of observations was 421.

Weather records were kept on the Crossett Experimental Forest from 1934 through 1973. Average annual precipitation for the 40 years of record was 53.34 inches. Figure 1 shows the average monthly rainfall for the period. It is highest in the winter months and declines during the growing season through October, except for a mild increase in July. Summer droughts are common; the average growing season rainfall (March through October) is 33.49 inches, but it has ranged from 19.24 to 56.36 inches.

Monthly summaries of these data were used to compute different measures of growing season rainfall during each growth period. For example, if the growth period occurred in the years 1955 to 1958, the different growing season rainfalls for this period would be accumulated for this growth observation. The different rainfall variables were the cumulative amounts for the following groups of months: March through October, March through May, June through August, and July through September. June, July, and August were included as individual months to

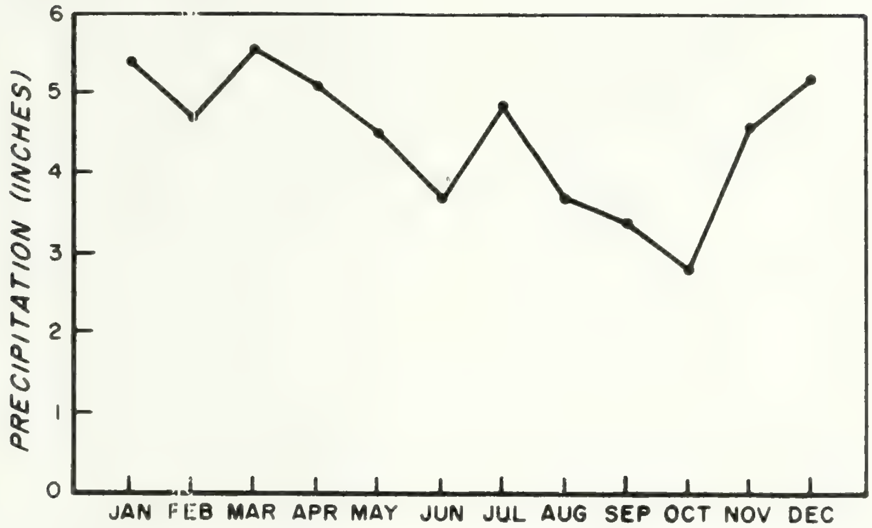


Figure 1.--Average monthly precipitation, 1934 to 1973, Crossett Experimental Forest, south Arkansas.

assess the relative importance of each of the summer months to basal area growth.

ANALYSIS

The basal area projection equation originally used by Moser and Hall (1969) for uneven-aged stands and later by Murphy and Farrar (1982) was selected for this investigation. It is the Chapman-Richards function and may be written in the following form for our analysis:

$$(1) \qquad B_2 = [p_1-(p_1-B_1^{\,p_2})\exp\{p_2p_3t\}]^{(1/p_2)},$$

where

$B_1$ = basal area ($ft^2$ per acre) at start of period,
$B_2$ = basal area ($ft^2$ per acre) at end of period,
$t$ = period length in years,
$p_i$ = parameters to be estimated, and
exp = exponent of e.

A desirable feature of any growth and yield model is predictive invariance, that is--projecting from times $t_1$ to $t_2$ and then to $t_3$ ($t_1<t_2<t_3$) gives the same answer as projecting from $t_1$ to $t_3$ in one step. Deriving a projection model, such as equation (1), by integrating a growth model guarantees that the resulting projection equation will have this property.

An attempt was initially made to incorporate rainfall as a variable in addition to elapsed time and simultaneously preserve the predictive invariance of equation (1). However, this attempt was unsuccessful. The measure of rainfall ($r_i$) was used in lieu of elapsed time as an alternative approach,

$$(2) \qquad B_2 = [p_1-(p_1-B_1^{\,p_2})\exp\{p_2p_3r_i\}]^{(1/p_2)},$$

where the other variables are as previously defined. Equation (2) has the property of predictive invariance. Thus, nine models were tested: equation (1), using elapsed time, and equation (2), using eight different growing-season rainfall variables ($r_i$). The nine models were fitted by nonlinear least squares (Dixon 1981).

A set of 306 observations was randomly selected from the original data to conform to software limitations on the number of observations and variables; the random selection procedure was modified to obtain a more rectangular distribution of data than was in the original data set. The statistics for the final 306 observations are:

| Variable | Mean | Standard deviation |
|---|---|---|
| | -------------- $ft^2$ -------------- | |
| $B_1$ | 48.7 | 17.5 |
| $B_2$ | 62.5 | 20.1 |
| | -------------years------------- | |
| t | 5.1 | 2.0 |
| Rainfall | ------------inches------------- | |
| Mar-Oct | 169.0 | 67.1 |
| Jun-Oct | 93.7 | 37.8 |
| Mar-May | 75.3 | 31.5 |
| Jun-Aug | 63.5 | 26.7 |
| Jul-Sep | 58.8 | 23.2 |
| Jun | 20.6 | 9.9 |
| Jul | 23.7 | 10.2 |
| Aug | 19.3 | 9.1 |

The rainfall statistics are for cumulative rain during the growth period; they are not annual.

Table 1 gives fit statistics for the nine equations. The equation using July-September rainfall performed the best overall according to the fit criteria, although the improvement over elapsed time alone was real dramatic. All other equations gave results worse than the basic model. The results for June, July, and August indicate that July rainfall explains more variation than either June or August; a rationale might be that variation in rainfall is greater in July than either June or August and, consequently, contributes more to basal area growth.

Table 1.—Fit statistics for different basal area projection models

| Variable | M.S.E.[1] | Fit index[2] | Bias[3] | Absolute deviation[4] Mean | Standard deviation |
|---|---|---|---|---|---|
| | | | $ft^2$ | | |
| Time | 59.03 | 0.852 | -0.301 | 5.33 | 5.28 |
| Mar-Oct | 59.08 | 0.852 | 0.339 | 5.54 | 5.28 |
| Jun-Oct | 57.35 | 0.857 | 0.383 | 5.43 | 5.23 |
| Mar-May | 67.12 | 0.832 | 0.880 | 5.91 | 5.62 |
| Jun-Aug | 61.03 | 0.847 | 0.509 | 5.65 | 5.35 |
| Jul-Sep | 53.78 | 0.866 | 0.173 | 5.32 | 5.00 |
| Jun | 68.66 | 0.828 | 1.049 | 5.95 | 5.71 |
| Jul | 65.21 | 0.837 | 0.714 | 5.88 | 5.48 |
| Aug | 67.48 | 0.831 | 1.041 | 5.94 | 5.63 |

[1] M.S.E. = estimated mean square error
[2] Fit index = $1 - \sum(y_i - \hat{y}_i)^2/\sum(y_i - \bar{y})^2$
[3] Bias = $\sum(y_i - \hat{y}_i)$
[4] Absolute value = $|y_i - \hat{y}_i|$

## CONCLUSION

These preliminary results show that including growing season rainfall, notably July-September, does increase the predictive power of the basal area projection equation used here. The gains are somewhat modest, because initial basal area and elapsed time do a good job of describing basal area development in the original model.

Further investigation is warranted to determine which combination of months are best. Since the months should be contiguous, the number of equations to test are large but not overwhelming. There are 8 growing season months; therefore, there are 36 possible combinations of contiguous months varying from 1 to 8 months in length.

Another approach worth studying is the inclusion of soil-water budgets. Fortunately, this approach will soon be facilitated by a software package by Zahner[3] that calculates potential evapotranspiration and soil-moisture deficiencies along with an index of how much potential tree growth is affected on a daily basis.

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## Pest Management

Moderator:

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Impact of Pine Tip Moth Attack on Loblolly Pine Seedlings[1]

Roy L. Hedden and D. A. Haugen[2]

ABSTRACT.--Impact of Nantucket pine tip moth attack on height, diameter and biomass of 3 year-old loblolly pine trees was measured in a planted stand in northwestern South Carolina. Twelve, 0.25 acre plots were established in 1984, and in 1985 two insecticide treatment regimes were applied to 8 of the plots. In four plots, the insecticide sprays were applied three times to coincide with the three annual tip moth generations, while in the other four insecticide plots, sprays were applied to only the spring generation. Four of the plots were untreated check plots. In each plot, 25 measurement trees were tagged during the 1984 growing season. The height and diameter of each tree at the end of the 1984 and 1985 growing seasons was measured. Furthermore, five trees were selected at the end of the 1985 growing season from each of the check and three-spray plots for biomass sampling. Statistical analysis of the data revealed that there were significant ($P < .05$) differences in height at the end of the 1985 growing season between the insecticide and the check treatments. Significant differences in diameter occurred only between the three-spray and the check treatment. There were also significant differences in estimated biomass between the check and three-spray treatments. However, a single combined regression equation based on $\ln(y) = a + b \ln(D^2H)$ adequately described the relationship between biomass (foliage, branch, stem and total) and diameter and height for both treatments. This analysis suggests that the impact of the Nantucket pine tip moth on loblolly pine results from attacks preventing full development of potential photosynthetic area. The importance of these differences to long-term impact of Nantucket pine tip moth is discussed.

## INTRODUCTION

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a well known pest of loblolly and other species of southern pines. Numerous studies have been conducted to estimate its impact on young pines, but the circumstances where control are warranted are still not well defined. In virtually all cases, the studies show reduced diameter and height growth in younger trees, however some long term studies indicate that reduction in height growth is transitory (Warren and Young 1972; Shepard 1973; Stephen et al. 1982). Even though reductions in height may be temporary, tip moth (NPTM) impact on diameter is real and persistent, resulting in a significant reduction in volume (Williston and Barras 1977; Cade and Hedden, In press). Tip moth attack may result in other forms of impact in addition to growth loss. For instance, Hedden and Clason (1980) suggest that NPTM attack also can cause reductions in wood and lumber quality.

The NPTM also interacts with other pests to cause greater damage than when either pest is found alone. Herbaceous weed control results in higher levels of tip moth attack due to an increased number of and more nutritious shoots available for attack (Hedden and Nebeker 1984; Nelson and Cade 1984). Increased numbers of attacks can provide a continuous supply of infection courts for the pitch canker fungus (S. C. Cade, personal communication). Furthermore, NPTM attack has been related to a significant increase in fusiform rust infection (Powers 1985). These potential interactions, combined with the direct impact of NPTM attack on tree growth and quality, suggest that as the intensity of forest management increases, the importance of pine tip moths as pests of loblolly pine will also increase (Hedden and Nebeker 1984).

In order to better understand the interaction of the NPTM with loblolly pine, we initiated a study in 1984 to investigate the impact of tip moth attack on tree growth. Numerous other studies have been conducted to investigate the impact of pine tip moth attack on diameter, height, and volume growth, but none of these efforts, with the possible exception of Hedden et al. (1981), has attempted to provide a detailed description of how NPTM effects tree growth. In the research reported herein, we show how the NPTM prevents the development of potential photosynthetic area, and how this reduction in leaf area affects tree growth.

[1]Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

[2]Professor and Research Associate, Department of Forestry, Clemson University, Clemson, South Carolina.

## PROCEDURES

### Study Site

The plantation is on a cut-over pine site on the Clemson University Experimental Forest in Pickens County, South Carolina. The previous stand was harvested in July 1981. The site was prepared by hand-clearing, piling in windrows and rootraking in October 1983. Improved loblolly pines were machine planted at a nominal 8 by 10 foot spacing during February 1984. The site consists of gently rolling hills (slopes of 4% or less) typical of the upper Piedmont of South Carolina. The major soil series is a Hiwassee sandy loam with a small amount of Madison sandy loam. The average site index, for shortleaf pine, of the previous stand was about 80 feet (base age 50 years).

### Experimental Design

Four blocks, each 3/4 acre, were established in the fall of 1984. Blocking was done on the basis of slope and soil type, with 3 blocks of Hiwassee sandy loam and 1 block of Madison sandy loam. The blocks consisted of three 1/4 plots, each of which was randomly assigned one of 3 treatments in 1985. Each plot was separated from every other by at least 1 or more buffer rows. Treatment 1 ("one-spray") consisted of one spray of fenvalerate (.16 oz/gal a. i. [.024% a. i.]) timed to coincide with the presence of the 1st-instar NPTM larvae of the overwintering pine tip moth generation in 1985. Treatment 2 ("three-spray") consited of 3 fenvalerate sprays timed to coincide with the presence of 1st-instar larvae in each of the 3 annual NPTM generations in 1985. Treatment 3 ("check") consisted of unsprayed check plots. Permanent 25-tree measurement plots were established by tagging 5 adjacent trees in the inner 5 rows in each of the larger treatment plots. Plot measurements of height, basal diameter and the proportion of growing tips infested by the NPTM were made during the winters of 1984 and 1985.

### Biomass Sampling

During the winter of 1985, 20 trees each from three-spray and check treatments, for a total of 40 trees, were sampled for biomass. Five trees in each treatment were taken from each block. The sample trees were selected to represent the size classes present in the measurement plots. Each tree was subdivided into its component parts: stem, branches, and foliage (old and current). Current foliage was the needles from the last growth flush while old foliage was all other needles. The total dry weight of each component was determined to the nearest gram. The dry weight of each component was modeled as ln(weight) = a + b $\ln(D^2H)$ where D = basal diameter (mm) and H = total height (cm). In addition to biomass, leaf area using the volume displacement method was determined for old and current foliage following the procedure of Johnson et al. (1985).

## RESULTS AND DISCUSSION

At the end of the 1984 growing season there were no significant differences in year-end percentage of tip moth infested shoots (18.61 ± sd = 22.35%) and at the beginning of the 1985 growing season there were no significant differences in height (37 ± 12 cm) or basal (ground line) diameter (8 ± 2 mm) by block or treatment. However, by the end of the 1985 growing season there were significant differences between treatments for some of the variables (Table 1). Significant differences in height and infestation level were found between the three-spray and the other 2 treatments, but no noticeable differences were found for any of the variables between the one-spray and check treatments.

Table 1.--Treatment means for height, basal diameter and year-end infestation in 1985.

| Treatment[1] | Height | Basal diameter | Infestation level |
|---|---|---|---|
| | (cm) | (mm) | (%) |
| Check | 101a[2] | 20a | 44.3a |
| One-spray | 103a | 20a | 41.3a |
| Three-spray | 111b | 22a | 1.3b |

[1] No. of trees/treatment = 100

[2] Means with different letter are significantly different at $p < .05$.

The biomass subsample consisted of 20 trees from the three-spray and 20 trees from the check treatment. The mean height, basal diameter and % infested shoots for the check treatment were 99.7 ± 23.3 cm, 19.45 ± 6.1 mm, and 34.2 ± 16.6 %. In the three-spray treatment the mean height was 113.5 ± 25.3 cm, mean basal diameter was 21.1 ± 4.6 mm, while the tip moth attack rate was 4.5±5.7 % of the buds infested. These values are very similar to the mean values for the trees in the measurement plots (Table 1). The leaf area and biomass values for these treatements are given in Table 2.

The distribution of biomass in the trees is similar even though the weight of the individual components is always less in the check treatment. About 55% of the biomass is foliage with the stem and branches making up 32% and 13%, respectively. Also, relative leaf area (leaf area/foliage weight) is very similar in both the check and three-spray trees. Indeed, an analysis of covariance showed that a single equation for each biomass component was adequate to describe the functional relationship between the variables (weight and basal diameter and height) for each treatment (Table 3).

Table 2.--Dry weight and leaf area for the check and three-spray treatments.

| Variable | Check | Three-spray |
|---|---|---|
| Total tree (g) | 137.8 | 191.5 *[1] |
| Stem (g) | 45.0 | 60.0 |
| Branches (g) | 17.3 | 23.1 |
| Foliage (g) | 75.5 | 108.4 * |
| Leaf area ($cm^2$) | 9,383.4 | 13,213.0 * |
| Relative leaf area ($cm^2/g$) | 124.3 | 121.9 |

[1]* means significantly different at $p < .05$

Table 3.--Values for biomass regression equations for dry weight (gm) for tree components for the check and three-spray treatments. Equation form: $\ln(W) = a + b \ln(D^2H)$.[1]

| Tree component | Intercept (a) | Slope (b) | R2 | Sy.x |
|---|---|---|---|---|
| Total tree | -3.37034 | .78221 | .88 | .22643 |
| Stem | -5.08071 | .83445 | .92 | .19674 |
| Branches | -6.69000 | .88787 | .76 | .38772 |
| Foliage | -3.44146 | .73546 | .84 | .24972 |

[1]W = weight in gm, D = basal diameter (mm) and H = total tree height (cm).

Most of the difference in biomass between treatments is due to the difference in foliage weight (table 2). Tip moth attack represented a reduction in leaf area and foliage biomass of about 30%. This impact is much greater than the the 10% reduction in height and diameter or the 18% difference in volume ($D^2H$) for 1985. This indicates that the impact of NPTM attack is not totally expressed in the current year's volume. Impact in 1986 will partially be due the reduction in leaf area in 1985 plus the reduction which occurs in 1986. This pattern of impact will continue until after the trees are large enough to escape significant NPTM attack (Cade and Hedden, in press). Therefore, the net effect of attack is to delay the development of leaf area. This delay in combination with the early reduction in height increment lengthens the juvenile period of growth for the tree. This may be very important in prolonging the amount of time the tree may be exposed to pests of young trees in addition to the NPTM, especially fusiform rust where years of heavy inoculum production only occur periodically.

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# A CROWN RATING METHOD FOR ASSESSING TREE VIGOR OF LOBLOLLY AND SHORTLEAF PINES[1]

R. L. Anderson and R. P. Belanger[2]

Abstract.--Crown rating methods are commonly used in Europe to assess tree and stand vigor. Similar methods have not been developed for southern tree species. Because of recent concerns related to growth loss and forest decline in the South, a European method based on (1) percentage of foliage loss and (2) color of foliage was tried, modified, and tested on loblolly and shortleaf pines in the Piedmont of Georgia and South Carolina. This paper presents relationships between these crown vigor ratings and incremental radial growth. Results indicate crown density can be used to easily and quickly assess the relative tree and stand vigor of loblolly and shortleaf pines. Findings have silvicultural, forest management, and pest management implications.

## INTRODUCTION

Foresters collect a variety of information in the normal management of a forest stand. Species, age, soil, site index, radial increment, and basal area data are routinely collected to better understand the characteristics of the stand and potential productivity of the site. Soil and site conditions influence management decisions such as species selection, site preparation methods, potential pest strategies, and determining rotation lengths. Variables such as age, radial increment, and basal area help determine thinning and harvesting schedules. In the process of collecting these data, crown class and live crown ratio are often observed but, in most cases, little use is made of this information.

Many silvicultural practices such as thinning and timber stand improvement are directed toward improving crown development and subsequent tree vigor. Foresters began looking at the crowns on western pine species in the early 1930's (Dunning 1928, Keen 1936). Salman in the 1930's and 1940's developed a crown characteristics system on ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws.) to predict susceptibility to bark beetle attacks (Smith and others 1981). In 1936, Keen developed an age and crown vigor classification system for ponderosa pine. In the 1950's, Hall developed a detailed crown classification system, also for ponderosa pine, that used needle conditions, twig and branch conditions, and top crown conditions (Hall 1951, 1958). In 1962 (Smith and others 1981), a risk rating-system using crown conditions was further tested and has been expanded to other species, such as true fir (*Abies* spp.).

The relationship between crown conditions and radial growth of individual trees has been examined for loblolly pine (*P. taeda* L.). Guttenberg (1953) found that fast-growing trees have longer and wider crowns than slow-growing trees. Deetlefs (1954) showed that doubling the crown-length ratio about doubled the basal area growth of individual trees as a result of a fourfold increase in relative crown surface. Grano (1957) reported that seed trees with dense crowns grew faster in diameter than trees with average or sparse crowns. Crown lengths and live crown ratio are strongly influenced by stand density. It is not known how stand conditions affect crown density.

Crown classification systems have largely been ignored for shortleaf pine (*P. echinata* Mill.). An exception to this would be the research reported for littleleaf disease. Symptoms associated with this disease are expressed by a decline in general vigor and appearance of the crown. Guidelines are available for recognizing symptoms, evaluating the extent of the problem, and making management decisions (Anderson and Mistretta 1982; Campbell and Copeland 1954; Belanger, Hedden, and Tainter 1985).

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Crown vigor classifications have received considerable attention in Europe. A general decline in forest growth was reported in Germany around 1979 and had increased from 8 percent of the population of trees involved in 1979 to about 50 percent in 1984 (Schutt and Cowling 1985). Many symptoms were observed for the affected trees: foliage loss, yellowing, decreased growth, loss of feeder roots, decreased diameter increment, death of older needles and leaves, and increased susceptibility to root and foliage pathogens. To assess this problem, nationwide surveys in Germany were begun in 1982 and are redone during a 5- to 6-week period each year. Sample plots are established throughout most of the country on a 2.5 x 2.5 mile grid. A number of site parameters are collected, but two of the key parameters are percentage of foliage loss and foliage yellowing (Schroter and Aldinger 1985). These are combined to produce a damage rating for each tree and examined for each plot. The cause of the foliage loss or yellowing is not determined. However, it is generally felt that the condition of the crown reflects the vigor and health of the tree.

Major reductions in the growth of yellow pines have recently been reported in the southeastern United States (Sheffield and others 1985). Possible causes have been listed as atmospheric deposition, increased stand density, increasing stand age, increasing competition from hardwoods, drought, reduction in the water table, loss of old-field conditions, and increased impacts of insects and diseases. Since crown classification methods are used to successfully evaluate tree vigor and subsequent growth in Europe, a similar system was needed to visually evaluate the relative tree and stand vigor of southern pines.

This study was designed to examine the relationship between crown conditions and radial increment for loblolly and shortleaf pine at various ages. If a correlation was found, then findings could have meaningful and beneficial implications for any forest management decision that uses vigor as a variable. Examples would be pest hazard rating, thinning, determining rotation age, and establishing stand treatment priorities.

## METHODS

Ten shortleaf pine stands from South Carolina and 11 loblolly pine stands from Georgia were selected for study. Each stand, at least 5 acres in size, had to be naturally generated, with the majority of the trees in the same age class. Stands had to be at least 20 years of age and not over 80. Every attempt was made to obtain a uniform distribution of stands from 20 to 80. All stands had to be free of recent disturbances such as fire, bark beetles, and thinning.

In each stand, five sample points were selected at random to determine average stand, site, and individual tree characteristics.[3] Stand characteristics included pine basal area, hardwood basal area, and percentage of the pine component by species. Tree characteristics included diameter at breast height, total height, age, and radial increment for the last 5 years. Site index for loblolly and shortleaf pines was calculated from age and height of dominant and codominant trees (Schumacher and Coile 1960). The Campbell and Copeland (1954) field-rating system for evaluating littleleaf disease hazard was recorded for each stand. This required an evaluation of erosion, subsoil consistency, zone to depth of reduced permeability, and subsoil mottling.

Crown vigor was assessed in July 1986. Annual needle growth and crown development was at its maximum at this time. In each stand 20 trees were selected for crown evaluation. The trees could not be on the edge of the stand or have major damage such as fusiform rust or storm breakage. The European crown vigor method used four classes of percentage of needle loss (0-25, 26-50, 51-75, and 76-100) and three classes of yellowing (0-25, 26-60, and 61-100). We elected to use nine classes of needle loss ranging in percentages of 10 from 10 to 90. This gradation would provide more detailed information for statistical analysis, and could be regrouped into broader categories if needed.

Each tree was examined so the crown could be seen from the side by two people. Estimates of percentage needle loss were made by each person separately, compared, and adjusted until agreement was reached or averaged if not off by more than one class. To make the estimate, the portion of the crown containing some live needles was considered for observation (fig. 1).

The classification of crowns into the 10 percent crown class was relatively easy. In most cases, the two viewers agreed. If they did disagree, it was normally by a 10 percent difference. In those cases, the tree was assigned a value between the two observations--e.g., estimates of 30 and 40 percent foliage loss were rated as 35 percent. Every attempt was made to obtain a full range of density classes from 10 to 90 percent. Yellowing was assessed based on the percentage of yellow needles on the total crown.

The crown class and diameter at breast height were recorded for all sample trees. Each tree was bored at 4.5 feet and the core examined in the field. The radial increment in millimeters was recorded for the three most recent 5-year growing periods (0-5, 6-10, and 11-15 years).

Loblolly and shortleaf stands were analyzed as separate timber types. Age categories were classified as young (<40 years of age) and mature ($\geq$40 years).

[3]The authors thank Colleen Scarrow, Technician, Forest Pest Management, Asheville, NC, for assistance in data collection.

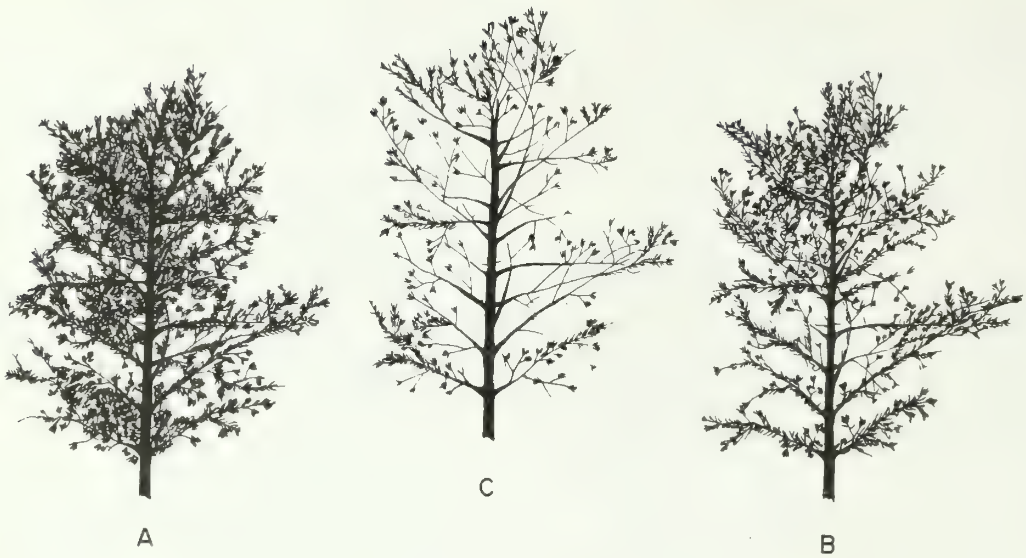


Figure 1.--Percentage of foliage loss was used to assess crown density. Examples are: A = 20 percent foliage loss, B = 60 percent loss, and C = 90 percent loss.

STAND AND SITE CHARACTERISTICS

The loblolly pine stands selected for the study were on the Chattahoochee-Oconee National Forest in Green, Jasper, and Morgan Counties, Georgia. The 11 loblolly stands averaged 45 years of age and ranged from 21 to 67 years (table 1). Average site index (loblolly at base age 50 years) was 81. This is higher than the mean of 76 reported for natural loblolly stands in the Georgia Piedmont (Brender 1973). Total basal area averaged 110 square feet per acre with a range of 74 to 134. Stand composition was predominantly loblolly pine.

Ten shortleaf pine stands were located on the Sumter National Forest in Union County, South Carolina.[4] They averaged 50 years of age with a range from 26 to 82 years. Average site index (shortleaf at base age 50) was 50. Total basal area averaged 91 square feet per acre. Variation in site index and total basal area was less for shortleaf pine stands than for loblolly stands.

Average radial growth, stem diameter, and total tree height was greater for loblolly pine than shortleaf pine. This is largely the influence of better site quality. There was little evidence of disease problems in the stands. The Campbell and Copeland littleleaf rating system classified 57 percent of the stands as moderate hazard; the remaining 43 percent were low hazard sites. All stands were generally in good health.

[4]The authors thank timber management personnel on the Chattahoochee-Oconee and Sumter National Forests for providing the information necessary to locate and select the study stands.

Table 1.--Characteristics of loblolly and shortleaf pine stands used to assess crown conditions and related radial growth

| Variable | Unit | Mean | Minimum | Maximum |
|---|---|---|---|---|
| | | LOBLOLLY PINE | | |
| Height--pine | feet | 75 | 43 | 106 |
| Age | years | 45 | 21 | 67 |
| Site index at 50 years | feet | 81 | 66 | 98 |
| D.b.h. pine | inches | 12.7 | 6.9 | 18.7 |
| Radial growth--last 5 years | millimeters | 10.2 | 5.0 | 18.0 |
| Pine basal area | $ft^2$/acre | 96 | 68 | 118 |
| Hardwood basal area | $ft^2$/acre | 14 | 2 | 48 |
| Total basal area | $ft^2$/acre | 110 | 74 | 134 |
| Loblolly | percent | 81 | 36 | 100 |
| Shortleaf | percent | 19 | 0 | 64 |
| | | SHORTLEAF PINE | | |
| Height--pine | feet | 58 | 39 | 76 |
| Age | years | 50 | 26 | 82 |
| Site index at 50 years | feet | 60 | 50 | 68 |
| D.b.h. pine | inches | 10.4 | 5.8 | 15.3 |
| Radial growth--last 5 years | millimeters | 9.0 | 4.2 | 13.4 |
| Pine basal area | $ft^2$/acre | 83 | 60 | 92 |
| Hardwood basal area | $ft^2$/acre | 8 | 0 | 16 |
| Total basal area | $ft^2$/acre | 91 | 60 | 104 |
| Loblolly | percent | 4 | 0 | 14 |
| Shortleaf | percent | 96 | 86 | 100 |

ASSESSING THE EUROPEAN SYSTEM ON SOUTHERN PINES

The crown rating system developed in Germany appears well suited for evaluating tree vigor associated with stand and damage conditions in European countries. However, the system was not particularly adaptable for evaluating the loblolly and shortleaf stands sampled in the Piedmont. Examination of 420 study trees indicated no need for assessing foliage color. Degree of yellowing was less than 25 percent for all trees. Although severe yellowing can occur on high-hazard littleleaf sites or nutrient deficient soils, results indicate a careful estimate of crown density alone can be used as a reliable estimator of tree and stand vigor.

## RELATIONSHIPS BETWEEN CROWN DENSITY AND RADIAL GROWTH

There was a general decline in the radial growth of trees as percentage of foliage loss increased (fig. 2). Correlations were stronger for young stands than for mature and overmature stands (table 2). There were little differences in correlation values between loblolly and shortleaf pines.

Figure 3 shows a plotting of data points for loblolly pine stands with the highest $r^2$ value. These plottings show that relationships between crown density and radial growth are strong for dense and sparse crowns but appear to weaken toward the 40 through 60 percent crown classes. This relationship was consistent for most of the stands sampled.

Sparse crowns obviously do not contain adequate needle surface area to support good growth, whereas dense crowns do. Reliable estimates of the percentage of foliage loss can be easily made for these two types of crown classes. It is more difficult to estimate crown density in the 40 to 60 percent range. Growth on these trees is also more likely to be influenced by variation in site quality and density that exists within any given stand. These factors--alone or in combination--could account for the wide variation in radial growth.

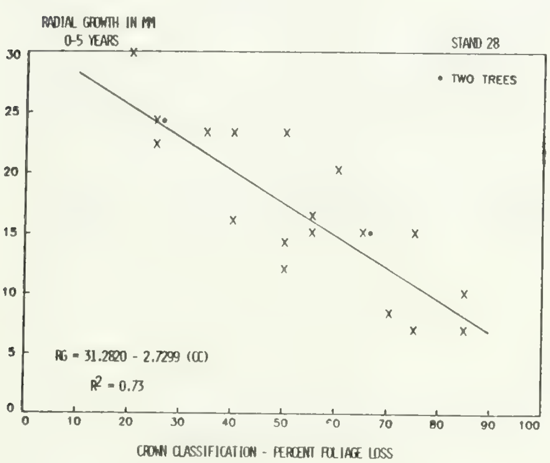


Figure 3.--Relationship between crown density and radial growth are strong for dense and sparse crowns, but weaker toward the intermediate crown density classes.

Several other correlations were examined. Relationships between crown density and tree diameters were significant but not as strong as correlations between crown density and 0-5 year radial growth. Radial increment for 6-10 and 11-15 years was examined. There was no significant correlation between these two measurements and the current crown vigor class.

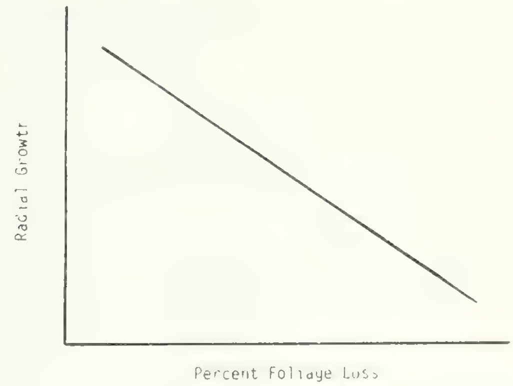


Figure 2.--Relative change in radial growth of loblolly and shortleaf pines associated with percent foliage loss.

Table 2.--Correlation between periodic radial increment (0-5 years) and crown vigor classification, for young and mature loblolly and shortleaf pine stands

| Stand age | Loblolly pine | | | Shortleaf pine | | |
|---|---|---|---|---|---|---|
| | Mean | Low | High | Mean | Low | High |
| | $r^2$ value | | | $r^2$ value | | |
| Young | 0.57 | 0.40 | 0.73 | 0.75 | 0.72 | 0.80 |
| Mature | 0.48 | 0.29 | 0.65 | 0.43 | 0.27 | 0.62 |

The data base was too limited to examine all combinations of age, site index, and stand density on crown classes and related growth. Confounding precluded isolating these variables independently. As expected, the strongest correlations were for individual stands. Yet, there was considerable variation in radial growth from stand to stand. For example, a tree with 50 percent foliage loss growing in a young, sparsely stocked stand would be growing at a rate quite different from that of a comparable tree growing in a mature, densely stocked stand. This means the method would be reliable to estimate radial increment for trees within a stand, but problems may result when making comparisons between stands.

## STAND VIGOR

Since crown condition influences individual tree growth, the distribution of crown density classes in stands can be used as an indicator of stand vigor and potential productivity. Figures 4 and 5 show the distribution of crown classes in young and mature loblolly and shortleaf pine stands. Distribution patterns for the different age divisions and forest types are quite different. For loblolly stands, trees tend to group around the 40 to 60 percent classes with a higher occurrence of trees with sparse crowns in older stands. Only a small percentage of loblolly pine trees in the study stands had dense crowns. It would be interesting to examine the

distribution of crown classes in stands treated to increase growth (e.g., fertilized and/or thinned). We anticipate the distribution would be skewed toward dense crown classes.

For shortleaf pine, trees were fairly well distributed from the 20 to 80 percent crown classes. Unlike loblolly pine, (1) a large percentage of trees in mature stands had dense foliage, and (2) a large percentage of trees in young stands had sparse foliage. Differences between loblolly and shortleaf pines may be attributed to site characteristics. Trees with dense crowns and good growth may be better able to cope with extreme weather conditions, competition and littleleaf disease than trees with sparse crowns. Site quality for loblolly pine was above average for the region and may not have influenced tree survival.

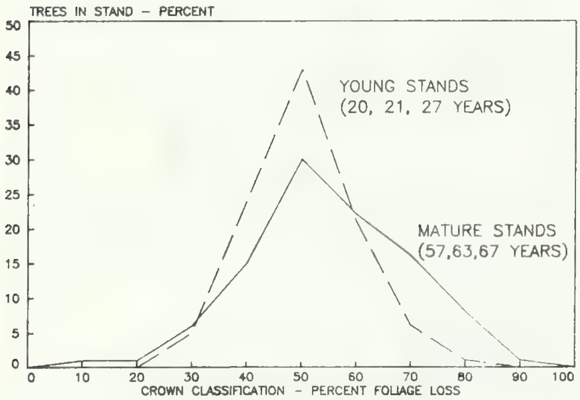


Figure 4.--Distribution of crown density classes in young and mature natural loblolly pine stands.

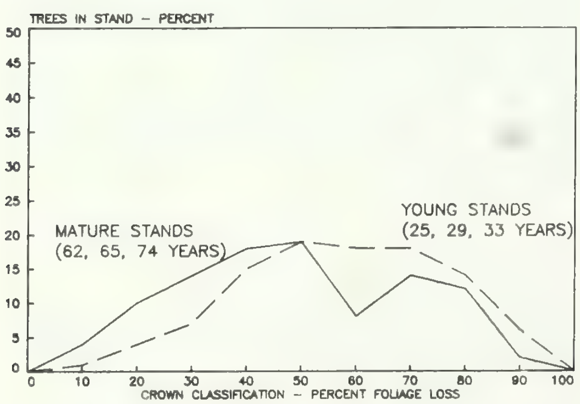


Figure 5.--Distribution of crown density classes in young and mature natural shortleaf pine stands.

## CONCLUSION

Tree growth is a complicated process. It is influenced by age, stand density, site quality, pest problems, genetics, and climatic factors. Annual or periodic radial growth are reliable means of measuring the effects of these variables on the general vigor of individual trees and stands. Yet measures of radial growth are not always easy to obtain. Some landowners object to quality sawtimber trees being bored to extract cores. Diameter measurements needed to evaluate periodic growth are not always available. It is expensive and time consuming to extract and process cores. Results from this study indicate careful assessments of crown density can be used to determine a relative measure of tree growth and vigor for (1) all trees in young stands and (2) trees with sparse and dense crowns in mature stands.

Crown density reflects the combined effects of branch and shoot development, branch and shoot retention, needle retention, and needle length. Crown density is a relatively easy measure to assess; it is more difficult to identify factors that influence this crown characteristic. A lack of moisture curtails shoot growth, needle length, and loss of branches (Copeland 1955). Heritability influences the number, size, and chemical composition of branches related to natural pruning. Results from this study indicate site quality and age are related to crown density. It is also likely that competition resulting from dense stocking influences needle length and needle retention. Many of these tree and stand characteristics can be influenced through tree improvement programs, stand establishment practices, and cultural measures during stand growth and development. Crown vigor should be maintained throughout the rotation. Poor growth associated with sparse crown may be an irreversible condition.

We do not suggest that crown density be used to determine precise measures of potential growth and yield. That would be an extreme oversimplification. We do conclude that crown characteristics can be used to assess the general health of individual trees and stands. We recommend that foresters examine and consider crown conditions when prescribing silvicultural treatments.

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# SELECTION OF SOUTHERN PINE BEETLE HAZARD RATING SYSTEMS FOR MISSISSIPPI[1/]

C. R. Honea, T. E. Nebeker, and J. D. DeAngelis[2/]

Abstract.--Seven southern pine beetle (Dendroctonus frontalis Zimm.) hazard rating systems developed for use in various parts of the southeast responded to changing site and stand conditions which effect the relative beetle hazard for private nonindustrial pine stands in Mississippi. Three of the systems were found to be more appropriate than the other systems. If radial growth data are available or can be obtained, one of two systems developed from data collected in Arkansas, Louisiana, and Mississippi is most appropriate depending on the level of hardwood control. If hardwood competition is maintained at a low level, a fairly simple system which uses only pine basal area and radial growth to indicate the relative hazard can be used. Stands containing more hardwood should be rated with the more complicated of the two systems which uses hardwood basal area as one of the inputs. If large areas are to be rated and ground inventory data are neither available nor obtainable, a system developed in Texas is appropriate for use with aerial photographs.

## INTRODUCTION

The southern pine beetle (SPB), Dendroctonus frontalis Zimm., has periodically disrupted timber management and the flow of resources from southern forests. A major effort has been directed at identifying site and stand conditions most frequently associated with SPB infestations (Ku et al. 1980, Kushmaul et al. 1979, Belanger et al. 1981). Rating systems have been developed which rate stands as to their relative susceptibility to SPB, and in one case (Mason 1981) to potential losses due to the SPB. These rating systems have generally been developed for specific geographic areas or from data bases with limited data types.

Although systems have been developed partially or entirely with Mississippi data, the data used were collected from relatively small portions of the state and may not fully describe the range of stand conditions found in Mississippi. Three SPB hazard rating systems were developed by Kushmaul et al. (1979) based on data collected in Louisiana, Arkansas, and Mississippi, and a system was developed by Sader and Miller (1976) from data collected in Copiah Co., Mississippi. It is desirable for a system to be validated with the full range of expected stand conditions before it is recommended for use. Therefore our objective was to compare the performance of several rating systems with pine stands from all Mississippi counties which have experienced problems with the SPB.

## METHODS

### Systems Selected For Comparison

Seven rating systems were selected for comparison, and for the sake of simplicity they will be referred to by number only (Table 1). Different developmental approaches were used with each system, and they are based on data from various parts of the southeast. Systems 1 and 4 may be used with generalized site and stand information acquired from aerial photographs to allow hazard rating on a large number of stands at relatively low cost, and system 2 was constructed such that it can be used with a minimum number of calculations. All seven use data which can be obtained from ordinary forest inventory information.

### Hazard Classes Generated

Hazard classes (Low, High, etc.) have been identified by these systems in various manners. Systems 1 and 4 identify five hazard classes, systems 2 and 3 have three classes, and systems 6 and 7 indicate if the stand would be expected to be infested or not. The probability of infestation is estimated by system 5. These various forms of hazard class determination make it difficult to compare the systems. We therefore altered the interpretation of the score determined by systems 2, 3, 5, 6, and 7 to generate five hazard classes (very low, low, medium, high, and very high) for each system.

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Table 1.--SPB hazard rating systems selected for comparisons.

| System Number | Variables Used | Area Where Developed | Reference |
|---|---|---|---|
| 1 | pine and hardwood basal area<br>average DBH | Copiah County, MS | Sader and Miller (1976) |
| 2 | pine and hardwood basal area<br>shortleaf pine basal area<br>radial growth (last 5 years)<br>live crown ratio<br>soil type | Georgia Piedmont | Belanger and Price (1979)[1/] |
| 3 | pine and hardwood basal area<br>age | Arkansas | Ku et al. (1979) |
| 4 | radial growth (last 10 years)<br>pine basal area<br>landform<br>total tree height | Texas | Mason et al. (1981) |
| 5 | pine and hardwood basal area<br>landform<br>age<br>disturbance (lightning or logging) | Gulf Coastal Plain | Hedden (1985)[2/] |
| 6 | pine basal area<br>radial growth (last 10 years) | Arkansas, Louisiana, Mississippi | Kushmaul et al. (1979) |
| 7 | pine and hardwood basal area<br>age<br>number of trees per acre<br>site index | Arkansas, Louisiana, Mississippi | Kushmaul et al. (1979) |

[1/] Belanger, R. P., and T. S. Price. 1979. The susceptible forest in the upper Piedmont. Fact Sheet. Ga. For. Comm., Macon, Ga. and U.S. Dep. Agric. For. Serv., Southeast. For. Exp. Stn., Asheville, NC. 1 p.

[2/] Hedden, R. L., and R. P. Belanger. 1985. Predicting susceptibility to southern pine beetle attack in the Coastal Plain, Piedmont, and southern Appalachians. In Integrated pest management symposium proceedings. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-56.

System 2 consists of six questions which are answered "yes" or "no"; the number of questions answered "yes" is used to indicate the relative hazard. One of the questions deals with the presence of micaceous red clay which does not occur in Mississippi, therefore the question was omitted. The remaining five questions were used as follows:

5 "Yes" answers = Very High Hazard

4 "Yes" answers = High Hazard

3 "Yes" answers = Medium Hazard

2 "Yes" answers = Low Hazard

1 or 0 "Yes" answers = Very Low Hazard

In order to calculate the probability of infestation with system 5 an estimate of the number of SPB infestations per 1000 acres of host type is required. This information was not available for the data used for these comparisons, therefore the range of probabilities was divided to create 5 hazard classes (Table 2).

Five hazard classes were identified for systems 3, 6, and 7 by dividing the range of discriminant scores (X) into five intervals (Table 2). These intervals were derived by calculating the mean discriminant score ($\bar{X}$) and standard deviation (s) of 62 infestations and setting the break points at $\bar{X} \pm .5s$ and $\bar{X} \pm 1.0$ s. Hazard classes were assigned for the resulting intervals as follows:

Very High = $X < (\bar{X} - 1.0\ s)$

High = $(\bar{X} - 1.0\ s) \leq X < (\bar{X} - .5\ s)$

Medium = $(\bar{X} - .5\ s) \leq X < (\bar{X} + .5\ s)$

Low = $(\bar{X} + .5\ s) \leq X < (\bar{X} + 1.0\ s)$

Very Low = $X > (\bar{X} + 1.0\ s)$

Altering the number of classes calculated by these systems changes the distribution of ratings

Table 2.--Generated hazard classes for systems 3, 4, 6, and 7.

| | Range of Scores for Each Class | | | |
|---|---|---|---|---|
| Hazard Class | System 3 | System 4 | System 6 | System 7 |
| Very High | <-41.37 | >0.8 | <-1.23 | <-1.2 |
| High | -41.37 to -6.0 | 0.6 to 0.79 | -1.23 to -.85 | -1.2 to -.68 |
| Medium | -5.99 to 64.76 | 0.4 to 0.59 | -.84 to -.09 | -.67 to .38 |
| Low | 64.77 to 100.14 | 0.2 to 0.39 | -.08 to .28 | .37 to .89 |
| Very Low | >100.14 | <0.2 | >.28 | >.89 |

for a given set of pine stands, but the median of the distribution is changed only slightly. It could be argued that these alterations essentially create a system other than the one originally presented. This is of little concern because the objective of this study is to identify a system or systems which will indicate the relative SPB hazard for Mississippi pine stands. It is not intended to necessarily validate an existing system for use in the state, therefore the results should not be used to judge the value of any one of these systems in other areas without careful consideration.

## Data Used For Comparisons

Four general data types were used for these comparisons. Information required by the selected systems is contained in data collected in Mississippi which represent the following data types:

1. The general population of loblolly and shortleaf pine stands.
2. Loblolly and shortleaf pine stands which contain recent SPB infestations.
3. SPB infestations which occurred during low SPB population levels.
4. SPB infestations which occurred during high population levels.

Mississippi Forestry Commission crews collected data from 511 private nonindustrial forest stands which were used to represent the general population of pine stands by placing one prism plot per five acres throughout each stand. Stands were selected from all counties which had experienced significant SPB infestations; at least ten stands were rated in each county. Stands were delineated using aerial photographs by homogeneity of timber type, age, and ownership. These stands were at least 20% pine with no restrictions placed on age, origin, disturbance, or SPB activity (past or present). The seven rating systems were used with the five classes described above to rate each sample point, and to rate the stand based on average stand parameters.

Stands with SPB activity within the last year (data type two) were located in 1983 with help from Mississippi Forestry Commission personnel. Once located, Mississippi Forestry Commission crews delineated and collected data on these stands as previously described. These 124 stands were rated in the same manner as those above.

Infestations which were found in the stands with recent SPB activity were used to represent the third data type because the SPB population was relatively low in 1983. Data for these 111 infestations were collected by placing a prism plot at the origin. This prism plot was in addition to those used for the stand as a whole.

Data were collected on 62 SPB infestations for the site/stand working group of the Expanded Southern Pine Beetle Program in 1977. These infestations occurred when the SPB population was high, therefore they will be used to represent the fourth data type. Most of the infestations were located in the Tombigbee National Forest and the Noxubee Wildlife Refuge with a few located in the Homochitto National Forest, and they ranged in size from 2 to 1050 infested trees.

## Evaluation Criteria

It is necessary to define desirable traits for the system which will be used in order to make meaningful comparisons. Since the hazard rating for a stand indicates the hazard relative to all other pine stands, the distribution of the ratings for all pine stands is expected to be normally distributed with most stands in the "medium" class. The system must be able to indicate stands which are more likely to lose trees to SPB if infestations occur. This does not mean all stands with infestations would be rated "high" or "very high". Most of these stands which have infestations will be rated "medium" because of the total number of stands in this class, and some will be rated "low" or "very low". Disturbance (i.e. - lightning or logging) leads to some of the infestations in these lower rated stands, and small areas of high tree density within the stands can become infested. However, the distribution of ratings for stands which have infestations is expected to be skewed to the higher classes, and the number of trees killed per acre of host type is expected to increase as the rating increases (Mason and Bryant 1984). The distribution of ratings for the infested "spots" is expected to be skewed even more to the high classes.

Additionally, variables which can be measured easily in normal timber inventory procedures should be employed by the system and each variable's effect on the hazard rating should be consistent with trends observed in the area of intended use. Sufficient variables should be used to allow the hazard rating to be sensitive to silvicultural practices such as hardwood control and thinning if they could be used to lower the hazard rating.

Statistical analysis can aid in these comparisons by indicating quantitative differences between systems. Pairwise comparisons were made using numerical rating classes (very low=1, low=2, medium=3, high=4, very high=5) with a sign test which ignores the magnitude of the differences; the test determines if the ratings from two systems have the same median (Conover, 1971).

## RESULTS

Many differences can be observed by comparing the hazard ratings produced by these seven systems from the four data sets. Pairwise comparisons among the rating systems indicate significant differences between systems with each data set. The ratings from system 7 have higher overall medians than the other six systems, and the ratings from systems 6, 3, and 4 have higher medians than do systems 1, 2, and 5 (Table 3).

Table 3.--Sign test results.

| Median rank | Hazard rating systems ranked by median numerical rating | | | |
|---|---|---|---|---|
| | GPS[1/] | SRA[2/] | ILP[3/] | IHP[4/] |
| Highest | 7 a* | 7 a | 7 a | 7 a |
| | 3 ab | 6 a | 6 a | 6 a |
| | 4 bc | 3 ab | 3 a | 4 ab |
| | 6 c | 4 b | 4 b | 3 ab |
| | 5 d | 5 c | 1 bc | 2 ab |
| | 2 d | 1 c | 5 bc | 5 b |
| Lowest | 1 e | 2 c | 2 c | 1 c |

* Systems followed by the same letter do not have significantly different medians (p<.05).

1/ GPS - general population of pine stands

2/ SRA - stands with recent SPB activity

3/ ILP - infestations during low SPB population

4/ IHP - infestations during high SPB population

Hazard ratings from systems 3, 6, and 7 for the general population of pine stands in Mississippi are approximately normally distributed, while the distribution of ratings from systems 1, 2, 4, an 5 tend to be skewed toward the lower hazard classes (Figure 1-A). The ratings for stands wi recent SPB activity are distributed generally in higher classes than are the ratings for the general population of pine stands for all of the systems (Figure 1-B), the ratings for the infestations located in these stands are distributed in even higher classes (Figure 1-C). Movement of the distribution of ratings to highe hazard classes as the data type changes from the general population of stands, to stands with recent activity, and to the actual infestations indicates that all of the systems are responsive to changing stand conditions which create more hazardous conditions.

It appears that the need for hazard rating in Mississippi can be met by using one of three systems. The decision of which one to use depen on available data, approach to data collection, and level of hardwood control. Systems 6 and 7 offer a distribution of ratings for the various data types which is very close to those expected and the variables in these systems are used in a manner consistent with trends observed in Mississippi. The distributions of ratings from system 4 are slightly less desirable, but this system uses variables which can be estimated fro aerial photographs. One of the variables used b system 4 is landform with three classifications (ridge, side slope, and bottom) none of which accurately describe the flatwoods area of Mississippi; for this comparison the flatwoods were classified as "bottom". These disadvantage with system 4 would easily be outweighed by the convenience and economics of using aerial photographs if ground inventory data were not available and large areas with numerous stands were to be rated. Systems 6 and 7 require data which can only be collected on the ground, but i is data that would be collected in normal inventory practices required for more intensive management decisons. System 6 is relatively simple since it uses only pine basal area and radial growth to calculate the hazard rating; th system would be most appropriate where hardwood controlled well enough to offer little competiti for the pine. System 7 is more complicated than the other two systems, but it offers more flexibility in the manner in which stand conditions can be manipulated to lower the hazar rating since more stand parameters are used. Therefore, system 7 would be more appropriate fo stands with larger hardwood densities.

## DISCUSSION

It is necessary to define the intended use of hazard rating system before its performance can evaluated. Ideally the system would indicate which stands will have large enough losses withi some time frame to justify treatment. However, predictions of this nature on a stand basis may not be obtainable. Pine timber management is complicated by many factors which should be considered in order to meet the objective for growing trees - whether financial or aesthetic. Potential loss to the SPB is only one of these

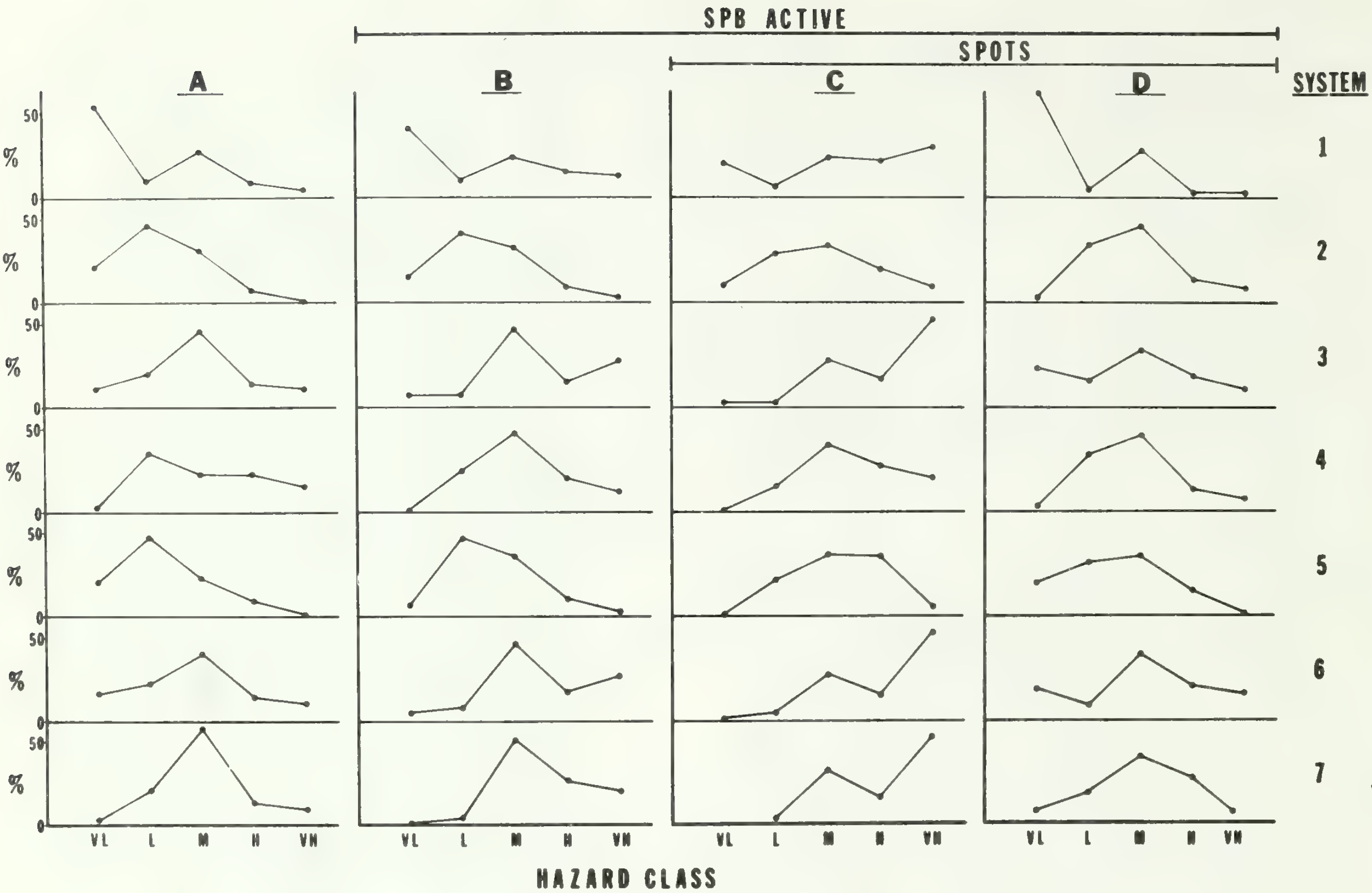


Figure 1.--Distribution of hazard ratings (VL-very low, L-low, M-medium, H-high, VH-very high) for seven southern pine beetle hazard rating systems (1-7) used with four data types (A-general population of pine stands, B-stands containing recent SPB activity, C-infestations during a low SPB population level, D-infestations during a high SPB population level) in Mississippi. Percentages (%) are the proportion of stands or infestations (spots) placed in a hazard class by one of the seven systems divided by the total number in the data type, therefore the sum of the points on each line should total 100.

considations. Taking action to reduce a high SPB hazard without considering other factors is not advisable. Harvest and thinning schedules should be established for a pine stand by considering all of the important factors, and the schedule should not automatically be altered due to a high hazard rating. Obviously there is little risk of incurring substantial losses if the SPB population is extremely low regardless of the hazard rating. Hazard ratings can be used to identify stands for which it may be advantageous to alter harvest or thinning schedules by indicating the SPB hazard relative to all other stands. They can also be used to assign a priority to several stands which are in need of treatment or to stands which have SPB infestations in need of control.

All of the systems place more of the "spots" which were infested during high levels of the SPB population into the lower classes (Figure 1-D) than the spots which were infested during low levels (Figure 1-C). Few stands are safe from the SPB during severe outbreaks, therefore the distribution of ratings for the infestations moves back toward the lower classes during these periods. This does not mean that hazard ratings are invalid during epidemics, because most of the losses will be contained in the stands rated "high" and "very high."

Rating individual sample points and dividing the stand or forest ownership into areas of similar hazard might be preferable to identifying a stand and rating the stand based on average stand conditions. Defining stand boundaries from aerial photographs or ground surveys can be difficult. Rating each sample point may not be practical if the calculations are done by hand. However, if a computer or programmable calculator is used for stand analysis and the data are recorded for each sample point, the stand division by hazard class is feasible. After the areas of common hazard are identified, it would be necessary to determine if there is a large enough area with conditions sufficient to justify altering harvest or thinning schedules.

The quality of stand management should not be judged by the hazard rating for the stand. Poorly

managed stands can be overstocked due to lack of attention or management objectives other than financial gain, or they can be understocked with pine due to excessive cutting or lack of hardwood control. Intensively managed stands will have proper stocking, and they will have conditions which will put them into the high rating classes before they reach economic maturity. Therefore, a high rating does not necessarily indicate improper management, and a low rating may not indicate a well managed stand.

Although the SPB can be very devastating, forest management should not be based entirely on eliminating losses from this one pest. Hazard rating has a place in forest management by identifying areas with high hazard to the SPB, relative to all other pine areas, where it may be advantageous to alter the harvest or thinning schedule.

Acknowledgements: The authors wish to thank Bill Lambert of the Mississippi Forestry Commission for his special assistance during the data collection phase of this study. We also wish to thank the many forestry students who participated in the data collection.

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EFFECT OF FUSIFORM RUST ON SURVIVAL OF LOBLOLLY PINE IN UNTHINNED PLANTATIONS[1]

Warren L. Nance and Eugene Shoulders[2]

Abstract.--The probability of survival for individual trees with and without fusiform rust stem cankers are compared using data from a large, long-term study of loblolly pine (Pinus taeda L.). The comparisons reveal a dramatic reduction in probability of survival for trees infected with fusiform rust stem cankers compared to their uninfected neighbors growing in the same stand under similar conditions. The probability of survival for trees with stem cankers is shown to be affected by the age of the tree when first infected with a stem canker, the tree's competitive status within the stand, and the tree's age. The various probabilities of infection, survival, and death in these data are summarized. The results of this investigation are briefly compared to those from a similar study of slash pine (Pinus elliottii Engelm.), and several management and modeling complications introduced by the disease are discussed.

## INTRODUCTION

Previous investigation of the slash pine portion in a site-species trial revealed that slash pine trees infected with fusiform rust stem galls had a much lower probability of survival than gall-free neighbors. An infected tree's probability of survival was related to the tree's relative size (competitive status) and age when first infected with a stem canker (Nance and others 1981).

The frequency of stem cankers and the probabilities of survival for individual stem-galled and gall-free loblolly pines from the same species-site trial are reported in this paper. The results for loblolly pine (Pinus taeda L.) are compared with those from the slash pine (Pinus elliottii Engelm.) portion of the study.

## THE STUDY

In the study, three plots of each of three species (loblolly, slash, and longleaf pine (Pinus palustris Mill.)) were planted in a randomized block design on uniform sites at 113 locations in Louisiana and Mississippi in the 1950's (Shoulders 1976). At age 20, there remained 146 loblolly pine plots (88 in Louisiana and 58 in Mississippi) at 60 locations with little or no fire, insect, or disease damage other than fusiform rust. All plots had been inventoried at identical ages: i.e., after 3 (Mississippi plots) or 5 (Louisiana plots), 10, 15, and 20 years. Each of these inventories provided individual-tree data on tree size and incidence of stem galls. Data from these plots were pooled to determine probability of survival or death, over time, of trees with and without one or more stem galls. Probability was further partitioned according to the tree's relative size, competitive status, and, for stem infected trees, the time in the tree's life that the first infection occurred (Shoulders and Nance 1986).

The loblolly pine seedlings planted in each state were grown from seed lots collected in that state. For slash pine, most of the installations (more than 80 percent) were grown from seed

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collected in southern Mississippi and the adjacent parishes in southeastern Louisiana where slash pine is indigenous. Seed for the remaining installations, all in Mississippi, were obtained from a Georgia seed dealer. Their exact geographic origin is unknown.

## CUMULATIVE RATES OF STEM INFECTION

In Mississippi, 35 percent of loblolly trees that were present at age 3 developed one or more stem galls by age 20 (fig. 1). Infection levels for loblolly pine were much lower in Louisiana than in Mississippi, averaging only 11 percent at 20 years for trees that were alive at 5 years.

This difference in infection levels between the two states in the loblolly pine portion of the study was surprising in view of the fact that the infection levels at age 20 for the slash pine portion of the study were essentially the same for both states (27 percent in Mississippi and 26 percent in Louisiana). Careful inspection of the data showed no differences in infection levels between the two sources of seed used to establish the slash pine installations.

## STEM-GALLED TREES

Since a tree's competitive status in the stand affects its ultimate fate, the trees in each state were partitioned into four height groups to study the probability of stem-galled trees to survive. The partitioning was accomplished by the following method. All trees within a plot were ranked according to height at 3 (Mississippi) or 5 (Louisiana) years without regard to their disease status. Each of these plot arrays was then subdivided into four groups of equal size with height group 1 containing the shortest one-fourth of the trees and height group 4 containing the tallest one-fourth. Finally, all trees within a state were pooled according to group position, and transitional probabilities were computed for each of the four height groups (Nance and others 1981).

In both states, the survival probability of stem-galled loblolly pine trees increased as the age when the gall was formed increased and as the tree's competitive position in the stand improved (figs. 2, 3). There were, however, important differences between states in the way the disease affected survival of trees in individual height groups.

For loblolly pines in the tallest height group, the probability for stem-galled trees to survive was always higher in the Louisiana than in the Mississippi population (fig. 2). This trend, together with the higher probability of infection in the Mississippi plots, resulted in heavier natural thinning from above in the Mississippi than in the Louisiana installations. A further consequence of this difference in rust-associated mortality in the tallest height group was that trees in the shortest height group were subjected to greater competitive stress at an early age in Louisiana than in Mississippi. Consequently, after age 10 the probability of survival among stem-galled trees in the shortest height group was lower in Louisiana than in Mississippi.

While trends were in the same direction, tree size had less effect on the probability for slash pine to survive with a stem gall (fig. 3). In the tallest height group, the probability for stem galled trees to survive was greater for loblolly than for slash pine. In the shortest height group, when stem galls were present, infected slash pine tended to survive longer than loblolly pine. The difference between the two species in persistence of trees in the shortest height group probably reflects a difference in the way the species respond to competitive stress.

As was the case with loblolly, the probability was greater in Louisiana than in Mississippi installations for stem-galled slash pine in the tallest height group to survive. But the difference between states was much less pronounced in slash than in loblolly pine.

## DISCUSSION AND CONCLUSIONS

The design of this experiment provided a unique opportunity to compare fusiform rust infection and transitional probabilities for unimproved slash and loblolly pine planted at the same time on the same sites across two states.

In Mississippi, the differences between the two species, both in infection level and probability of death with a stem canker, were quite small. One would find it difficult if not impossible to distinguish between the two species with respect to these traits.

However, the data from the Louisiana plots show large differences between the two species--with loblolly pine exhibiting much lower infection levels and probabilities of death with stem cankers than slash pine. Moreover, the slash pine in Louisiana was remarkably similar in infection levels and probabilities of death to the slash pine (and loblolly pine) populations in Mississippi.

Although there are many possible explanations for these results, the most plausible explanation is that the Louisiana source of loblolly pine used to establish the plots in Louisiana was genetically resistant to fusiform rust, whereas the Mississippi source of loblolly pine used in the Mississippi plots, as well as the slash pine used in both states, was not resistant to the disease. This explanation would be consistent with the rust resistance patterns described for provenances of loblolly

and slash pine reported previously by Wells and Wakeley (1966).

If genetic resistance did in fact result not only in lower infection levels but also in lower probabilities of death for trees with stem cankers, then the benefits of using genetically resistant material in high rust hazard areas would be twofold: the resistant trees would not only resist infection better than susceptible trees, but those resistant trees that did become infected with stem cankers would tend to survive better with the disease than similarly infected susceptible trees.

Most authors have assumed that the growth and yield benefits attributed to the use of genetically resistant planting stock can be modeled by simply lowering the infection levels for resistant stock compared to those expected for susceptible stock. The probability of death with a canker is then assumed to be the same for resistant and susceptible trees alike. Clearly, if the probability of death with a canker is lower for resistant trees, this effect would also have to be incorporated in any assessment of the benefits attributed to the use of resistant planting stock.

It should be emphasized that the data presented here merely suggests, and cannot provide a test of the hypothesis, that genetic resistance offers the dual benefits of lower stem infection levels and lower probabilities of death with stem cankers. More definitive data sets in which genetic resistance was a controlled feature of the experiment should be available to allow a test of the hypothesis.

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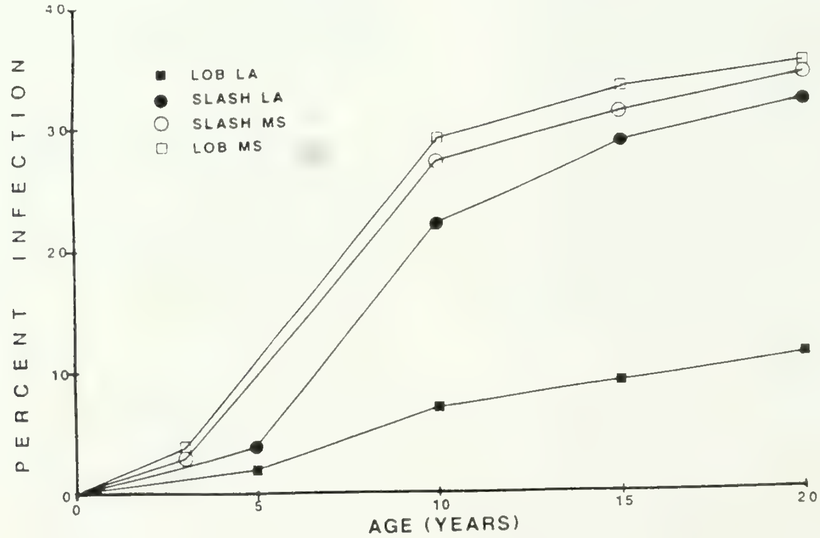


Figure 1.--Cumulative stem gall formation rates for loblolly and slash pine in Mississippi and Louisiana species trials.

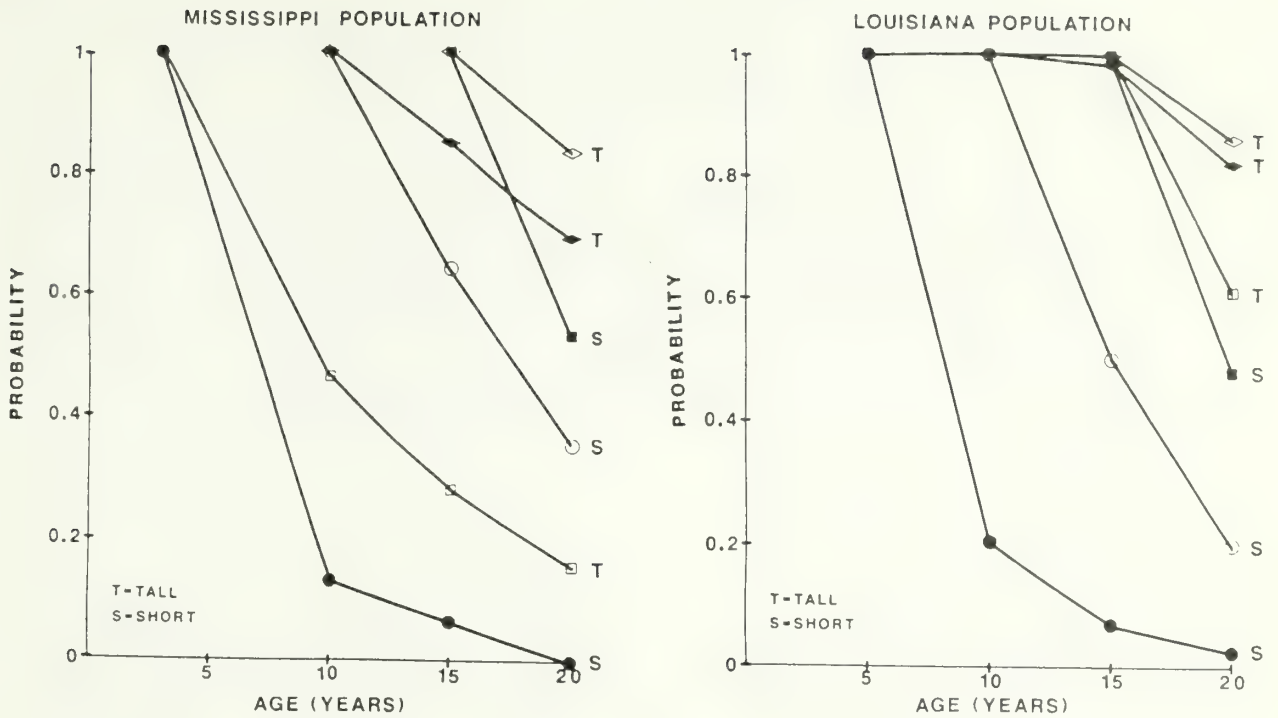


Figure 2.--Probability for survival of loblolly pine trees with stem-galls by location, age at time of detection, and competitive status.

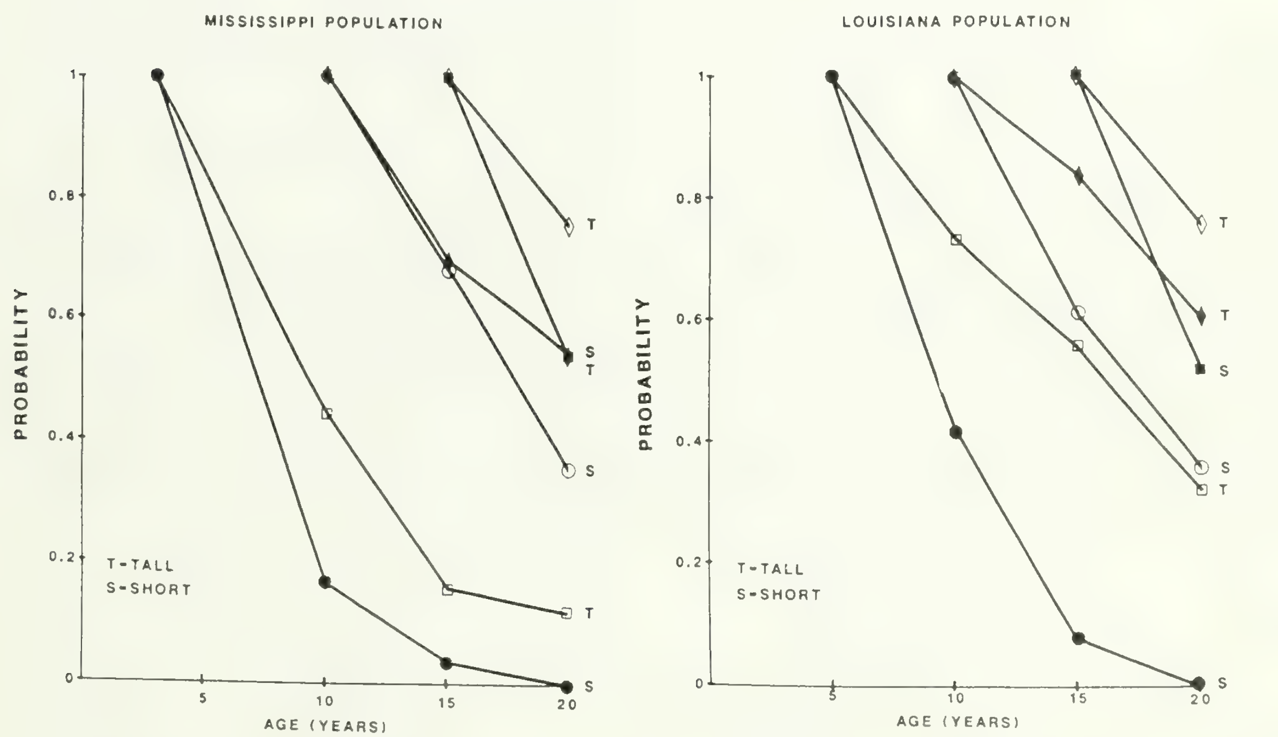


Figure 3.--Probability for survival of slash pine trees with stem-galls by location, age at time of detection, and competitive status.

# QUANTIFYING THE EFFECTS OF FUSIFORM RUST ON TREE BASAL AREA GROWTH IN SLASH PINE PLANTATIONS[1/]

W. Michael Harrison and L. V. Pienaar[2/]

Remeasurement data from slash pine (Pinus elliottii Engelm.) plantations in the Georgia, North Florida, and South Carolina coastal plain were used to compare the basal area growth of trees with and without Cronartium stem cankers (Cronartium fusiforme Hedgc. and Hunt ex Cumm). Analysis indicated that trees without stem cankers grew significantly more than comparable infected trees. A general distance-independent individual-tree basal area growth model was developed from permanent plot data remeasured over a nine-year period. The use of this equation for growth prediction purposes is demonstrated for hypothetical stands with various levels of Cronartium stem infections.

## INTRODUCTION

Fusiform rust, caused by the fungus Cronartium fusiforme (Hedgc. and Hunt ex Cumm.), is the most serious disease of the southern pines (Cowling et al., 1977, Jones, 1972). The most widely planted species in the southeast, slash pine (Pinus elliottii Engelm.) and loblolly pine (Pinus taeda L.), are also the most susceptible species to fusiform rust (Zobel and Zoerb, 1977).

Studies relating fusiform rust infection to the growth of individual trees have produced mixed results. Dell and Driver (1963) studied the diameter distributions of slash pine trees with and without stem cankers in the same stand. Their data showed that the average diameter of cankered trees was not significantly different from that of healthy trees and the diameter distributions were similar. Barber (1961) compared the sizes of healthy and infected trees several years after infection and found no significant differences. Froelich et al. (1983) found that early stem infection and more than 50 percent encirclement by rust of the main stem were required for significant decreases in height growth by the end of the sixth growing season after planting. In a study of slash pine plantations in South Carolina and Georgia, Powers et al. (1974) showed that the growth of severely infected trees was significantly reduced. Sluder (1977) found significant differences in mean volume per tree between stems with and without fusiform cankers. The average decrease in volume for cankered slash pine stems was 18 percent. Jones (1972) investigated height and diameter growth of infected and uninfected slash pine. He found that the growth of uninfected trees from age 6 to 16 was 6.8 percent greater in diameter and 7.8 percent greater in height than growth of infected trees over the same period. Neither of these differences was statistically significant. In a study of the effects of fusiform rust on growth of planted slash pine in Louisiana, trees were grouped into severity-of-infection classes. No significant differences in average dbh, height, and volume per tree were found between uninfected trees and trees with stem cankers extending less than halfway around the bole. Significant differences were found between trees with 50 percent or more of the circumference affected by rust and those with less than 50 percent of the stem circumference affected (Burns and Hu, 1985).

## DATA COLLECTION AND SUMMARY

To compare the growth of infected and uninfected slash pine trees, we used data from the University of Georgia's Plantation Management Research Cooperative Cronartium study. During the summer of 1976, 206 permanent plots were established in the flatwoods regions of South Carolina, Georgia, and North Florida. The plots occur across a wide range of initial planting densities, site indeces, ages, and Cronartium infection levels (Tables 1 and 2). The plots were remeasured every third summer since 1976. The last measurement was made in 1985. The 1976 and 1985 data from 137 plots were used in this study.

The nine-year data were summarized to show differences between surviving trees with and without stem infections, regardless of the apparent severity of the infection. The average dbh of the uninfected trees was larger than the average dbh of the infected trees on 36 percent of the plots in 1976 and on 54 percent of the plots in 1985. Uninfected trees showed an increase of 2.05 inches in quadratic mean diameter over the nine year period compared to a 1.84 inch increase in quadratic mean diameter for the infected trees.

1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 4-6, 1986.

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Table 1. Distribution of sample plots by age in 1976 and base age 25 site index.[3]

| Site index (feet) | Age (years) 5-10 | 11-15 | 16-21 |
|---|---|---|---|
| | number of plots | | |
| 30-55 | 13 | 25 | 17 |
| 56-65 | 26 | 15 | 16 |
| 66-76 | 14 | 5 | 6 |

Table 2. Distribution of sample plots by number of trees per acre and percent rust infection in 1976.

| Trees per acre | Percent rust infection 14-20% | 21-40% | 41-60% | 61-80% | 81-90% |
|---|---|---|---|---|---|
| | number of plots | | | | |
| 278-400 | 2 | 11 | 7 | 3 | 1 |
| 401-600 | 3 | 29 | 17 | 15 | 2 |
| 601-800 | 0 | 13 | 16 | 13 | 0 |
| 801-943 | 0 | 3 | 2 | 0 | 0 |

## STATISTICAL TESTS

Three statistical tests on the null hypothesis that uninfected and infected trees grow the same were done.

### Paired t-test I

Average increases in basal area for uninfected and infected trees were calculated for each plot and were regarded as paired observations. The mean difference in basal area growth (uninfected minus infected) was positive and significantly different from zero at the $\alpha = .05$ level.

### Analysis of covariance

To account for the effect of variability in initial tree basal area on basal area growth, an analysis of covariance was used to compare the growth of uninfected and infected trees. The analysis of covariance model is

$$y_{ij} = \mu + s_i + \gamma\,(x_{ij} - \bar{x}) + e_{ij}$$

where $y_{ij}$ = Basal area growth for the $j^{th}$ tree, infection level i,

$\mu$ = overall mean basal area growth,

$s_i$ = effect of infection level i,

$x_{ij}$ = initial basal area of the $j^{th}$ tree, infection level i,

$\bar{x}$ = mean initial basal area,

$\gamma$ = constant multiple effect of the amount by which the initial size $x_{ij}$ differs from the mean initial size $\bar{x}$,

$e_{ij}$ = random error component associated with $y_{ij}$,

i = 1 if tree was uninfected,

2 if tree was infected,

j = $1,2,\ldots,n_i$,

$n_i$ = the number of observations at infection level i.

The effect of Cronartium infection ($s_i$) is obtained by adjusting the means of the $y_{ij}$'s, the adjustment depending on the means of the $x_{ij}$'s. The t-test for the adjusted means must account for sampling error arising from the estimation of $\gamma$. The difference between the adjustment means is written

$$\bar{y}_1 - \bar{y}_2 - \hat{\gamma}(\bar{x}_1 - \bar{x}_2)$$

and the variance of this quantity is

$$\sigma^2_{y.x}\left\{\frac{1}{n_1} + \frac{1}{n_2} + \left[(\bar{x}_1 - \bar{x}_2)^2 / \sum_{i=1}^{2}\sum_{j=1}^{n_i}(x_{ij} - \bar{x})^2\right]\right\}$$

The estimate of $\sigma^2_{y.x}$ is the mean square error from the regression of y on x (Cochran and Cox, 1950, Draper and Smith, 1981, Searle et al., 1980).

T-tests were done for all plot averages and for nine combinations of age in 1976 and site index (Table 1). For the plot averages, uninfected trees had significantly better growth at the $\alpha = .05$ level. For the site/age classes, uninfected trees had a greater least squares mean basal area growth in each category. This difference was significant in two categories, age 10 and under with site index from 55 to 65 feet and at age 11-15 with site index below 55 feet.

### Paired t-test II

To further minimize the effect of differences in initial tree size on growth, an additional paired difference test was devised. Uninfected trees were paired with infected trees having the same dbh in 1976. These pairings were done within plots to minimize the effect of variability in growing conditions on growth. The mean difference (uninfected minus infected) from 217 pairs was positive and significantly different from zero at the $\alpha = .05$ level. Uninfected trees grew more than infected trees of the same initial size on the same plot.

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[3] Site index values were calculated using the equation developed by Newberry and Pienaar (1978).

## MODEL DEVELOPMENT

With data from 2227 trees, a linear model was developed to predict individual-tree basal area growth. Variables included in models developed by Daniels (1981), Alder (1979), and others were considered for this analysis. Their models could not be used in their entirity, however, as they were either distance-dependent or contained variables not available from common forest inventories.

Correlation coefficients were calculated to decide which variables and transformations of variables were linearly correlated with basal area growth. The natural log of basal area growth was not as highly correlated with independent variables as basal area growth or square root of basal area growth. The correlation coefficients for these two variables were nearly equal for each independent variable. Square root of basal area growth was chosen as the dependent variable to insure nonnegativity of growth estimates. Candidate independent variables were used in various combinations to predict square root of basal area growth. Models with and without intercept terms were fit to the data. We found that a model without an intercept term could better reflect the differences in growth between uninfected and infected trees.

The model chosen as the best for basal area growth prediction is

$$\sqrt{\Delta BA} = \beta_1 (dbh/A) + \beta_2 (BA/\overline{BA}) + \beta_3 (B) + \beta_4 (\sin^{-1}\sqrt{INF\%})$$

where $\Delta BA$ = square root of nine-year basal area growth,

$dbh/A$ = dbh divided by age in 1976,

$BA/\overline{BA}$ = tree basal area divided by plot mean basal area,

$B$ = basal area per acre in 1976,

$\sin^{-1}\sqrt{INF\%}$ = arcsine of the square root of the proportion of trees with stem cankers on a plot in 1976.

Since the hypothesis that trees infected with Cronartium grow less than comparable uninfected trees was substantiated by the testing procedures discussed earlier, dummy variables were introduced into the model. Dummy variables are variables that take two or more distinct levels as opposed to regular independent variables which can take values over some continuous range. Dummy variables are assigned levels to account for the fact that factors represented by the different levels have separate deterministic effects on the response variable (Draper and Smith, 1981). The dummy variable in this analysis is

$Z$ = 0 for trees not infected with Cronartium stem cankers

1 for trees infected with Cronartium stem cankers.

The dummy variable model is

$$\sqrt{\Delta BA} = (\beta_1 + \beta_{01}Z)(dbh/A) + (\beta_2 + \beta_{02}Z)(BA/\overline{BA}) + (\beta_3 + \beta_{03}Z)(B) + (\beta_4 + \beta_{04}Z)(\sin^{-1}\sqrt{INF\%})$$

An F-test was used to determine that a significant improvement in residual sum of squares was obtained by inclusion of the dummy variables to account for differences in growth between uninfected and infected trees.

F-tests on partial sums of squares were used to decide which, if any, coefficients were not significantly different from zero at the $\alpha$ = .05 level. The dummy variable coefficients for $BA/\overline{BA}$, B, and $\sin^{-1}\sqrt{INF\%}$ were not significantly different from zero and were removed from the model. The model for predicting the growth of uninfected and infected trees is

$$\sqrt{\Delta BA} = (\beta_1 + \beta_{01}Z)(dbh/A) + \beta_2 (BA/\overline{BA}) + \beta_3 (B) + \beta_4 (\sin^{-1}\sqrt{INF\%})$$

Least squares estimates of the coefficients are

$b_1$ = .56155326

$b_{01}$ = -.07913534

$b_2$ = .11864428

$b_3$ = -.00085433

$b_4$ = .07930449

The $R^2$ value is .578 with a mean square error of 0.0061. Figure 1 shows the predicted growth of an individual uninfected tree and an infected tree of the same initial size in a hypothetical stand.

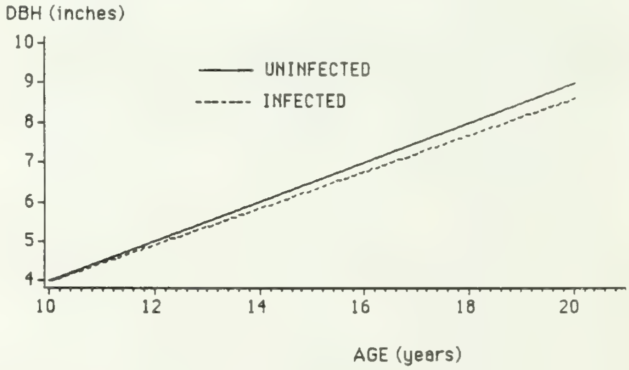


Figure 1. Dbh over age for individual trees in a stand with 55 sq.ft./acre of basal area and a 40% infection rate at age 10 years.

To demonstrate the utility of this model for growth prediction purposes, it was applied to hypothetical stands with 400 and 800 stems per acre at age 10 and various levels of Cronartium stem infections. Age 10 stand tables taken from Bailey et al. (1982) for site-prepared slash pine plantations were used for this purpose. Mortality

rates for uninfected and infected trees were calculated with equations developed by Clutter and Devine (1982). A FORTRAN program was written to simulate the development of the stands and output age-20 stand tables. Infection rates of 0, 20, 40, 60, and 80 percent were applied to each stand. With an initial density of 800 stems per acre, total basal area per acre at age 20 increased as infection rates increased from 0 to 20 percent, but decreased as infection rate increased from 40 to 80 percent. At a high initial density and relatively low infection rates, Cronartium seems to serve as a selective thinning agent thus allowing surviving trees to grow better. At higher infection rates, reduced growth and greater mortality among infected trees caused a decrease in the age 20 basal area per acre estimate. With an initial density of 400 stems per acre, basal area per acre estimates at age 20 decreased as infection rate increased from 0 to 80 percent. At this relatively low initial density, increased mortality associated with higher infection rates apparently did not benefit surviving trees. At a density of 400 trees per acre the intra-species competition is very likely having little effect on growth anyway. Figure 2 shows the development of the 400 and 800 tree per acre stands under different infection rates. At an infection level of 50 percent, both the 400 and 800 tree per acre stands showed about 10 sq.ft./acre less basal area at age 20 than a comparable stand with no Cronartium infection. At infection levels greater than 50 percent the loss in basal area at age 20 is greater in the 800 tree per acre stand.

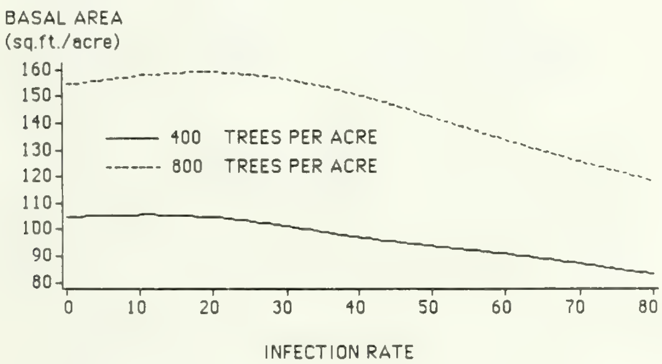


Figure 2. Plot of age 20 basal area per acre vs infection rate for stands with densities of 400 and 800 stems per acre at age 10.

## SUMMARY AND CONCLUSIONS

Data from 137 plots located in slash pine plantations in the coastal plain of Georgia, Florida, and South Carolina were used to examine the effect of fusiform rust on the basal area growth of slash pine. A paired comparison t-test on plot averages, analysis of covariance tests, and a test on paired trees of the same initial size on the same plot provided evidence to support the hypothesis that trees infected with Cronartium stem cankers grow less than comparable uninfected trees. Sluder (1977) and Jones (1972) found differences in average sizes of uninfected and infected slash pines although some differences were not statistically significant. Burns and Hu (1985), Powers et al. (1974), and Froelich et al. (1983) found significant differences in average tree sizes between severely infected trees and uninfected or less severely infected trees.

A growth model was developed to predict the basal area growth of infected and uninfected trees. Dummy variables were included in the model to adjust growth estimates for infected trees.

Because of the severity of rust infection in the South and its impact on growth and mortality of slash pine, managers must consider rust infection levels when estimating growth and yield of slash pine plantations. Clutter and Devine (1982), Nance et al. (1983), Borders and Bailey (1985), and others have incorporated rust infection considerations into growth and yield systems. Ideally, a growth and yield system which includes prediction of percent rust infection and separate estimates of growth and mortality for infected and uninfected trees should be developed to refine growth and yield estimates for slash pine plantations subject to fusiform rust infection.

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# MANAGEMENT AND PEST MANAGEMENT CONSIDERATIONS ON DROUGHTY SOILS: FOUR YEARS RESULTS[1]

David L. Kulhavy[2], Kenneth G. Watterston, James C. Kroll and James R. Meeker

Abstract.--Four year survival of pines on droughty (Typic Quartzipsamments) soils was best for longleaf pine and Terr-Sorb[R]-treated loblolly pine. Pest considerations include town ants and Nantucket pine tip moths on loblolly pine. Untreated loblolly pine had reduced leader and total height growth and increased tip moth infestations, compared to Terra-Sorb[R] and clay-slurry treated loblolly pine. Soil texture averaged less than eight percent silt and clay combined in the treatment areas.

## INTRODUCTION

Intensive site preparation and planting with genetically improved seedlings are widely used methods for southern pine regeneration. On droughty sites, clearcutting followed by these methods may lead to less than optimum results. While attempting to regenerate pines on droughty soils (= Tonkawa series), management and pest management options should be considered. Tonkawa soils, a Typic Quartzipsamment, consisting of excessively drained sandy soils on uplands, are characterized by low fertility with slopes ranging from 0-20 percent. In east Texas, these soils cover approximately 23,000 acres in Nacogdoches, Panola, Rusk and San Augustine Counties. Site index is approximately 55 (base 50 years). Original forest cover was probably dominated by shortleaf pine (Pinus echinata) with longleaf pine (P. palustris) intermixed. Dominant hardwood species were sandjack (bluejack) oak (Quercus incana).

In clearcut areas, with or without chopping, burning and/or shearing and windrowing and whole-tree chipping, regeneration is difficult due to the removal of organic matter and exposure of bare mineral soil to the sun and wind. This greatly decreases the moisture holding capacity of the soil as well as increasing surface temperature. Attempts to reforest these areas to pines often result in less than 10 percent survival. In 1983, a study was initiated to investigate management and pest management considerations, on these droughty soils. Kroll et al. (1985) reported the first two year's survival. This paper reports on four year results and additional management considerations.

## METHODS AND MATERIALS

Study plots were established on Tonkawa (Typic Quartzipsamment) soils (Dolezel 1980) 6 miles West of Garrison, TX. Seven treatments with eight replicates were established. Within each replicate, 48 seedlings were planted on an 8x8 foot spacing in four rows of 12 seedlings each. A buffer zone equal in size to the replicates was planted between and an the ends of each replicate with bare rooted loblolly pine seedlings. The seven treatments, randomly assigned in each replicate, were:

1. bare-rooted loblolly pine,
2. Terra-Sorb[R] [3] treated loblolly pine,
3. clay-slurry treated loblolly pine,
4. bare-rooted slash pine,
5. Terra-Sorb[R] treated slash pine,
6. clay-slurry treated loblolly pine, and
7. containerized longleaf.

Details of plot lay-out are presented in Kroll et al. (1985).

Terra-Sorb[R] is a starch-based synthetic acrylic polymer capable of absorbing water[3]. It forms a hygroscopic substance used as a root dip to increase moisture holding capacity. Clay-slurry is a similiar but inorganic compound also forming a hygroscopic substance when mixed with water. Replicates were hand-planted using standard methods in January 1983. The study was replicated in January 1984 and 1985 but failed due to excessively low winter temperatures, high rabbit predation, and drought and drying winds in 1984 and 1985, respectively.

Survival counts were taken at the end of the four growing seasons and data grouped to compare survival, differences in height growth, 1986 leader length and Nantucket pine tip moth, Rhyacionia frustrana, infestation rates. All data were analysed used one-way analysis of variance and means compared using Duncan's multiple range test at P = 0.05.

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[1] Paper presented at Southern Silviculture Research Conference, Atlanta, Georgia, November 4-6, 1986.

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## RESULTS AND DISCUSSION

Four-year survival is reported in Table 1. Note the steep decline in survival in the 1983-1984 growing seasons and the absence of significant mortality in the 1985-1986 growing seasons. At the end of the 1986 growing season, longleaf pine had 56 percent survival followed by 40.1 percent survival for Terra-Sorb -treated loblolly pine (P. taeda). Slash pine, P. palustris, had an average survival of 13 percent for all three treatments, combined.

Table 1. Survival of loblolly, slash and longleaf pine, Typic Quartzipsamments soils, four year results.

| Treatment | October 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|
| Longleaf Pine | 85.2 | 56.5 | 56.0 | 56.0 |
| Loblolly (Terra-Sorb[R]) | 81.3 | 50.8 | 46.5 | 40.1 |
| Loblolly (Clay Slurry) | 49.2 | 31.9 | 31.3 | 29.2 |
| Loblolly (Untreated) | 50.5 | 19.6 | 21.3 | 21.3 |
| Slash (Terra-Sorb[R]) | 46.9 | 20.8 | 16.2 | 14.6 |
| Slash (Clay Slurry) | 35.4 | 16.9 | 12.0 | 10.4 |
| Slash (Untreated) | 41.4 | 16.9 | 23.5 | 14.1 |

The decline in loblolly pine survival from 1984 to 1986 was due primarily to Texas leaf-cutting ants (town ants), Atta texana. Town ant predation is common on sandy sites (Moser 1984) and damage to pines is most severe in winter when there is little or no other green vegetation for the ants to forage (Thatcher et al. 1986). Currently, the Dowfume MC-2 formulation of methyl bromide, used for town ant control, and produced by Dow Chemical Company, is no longer available. The Texas Forest Service is involved with developing alternatives to methyl bromide for the control of town ants (R. Scott Cameron, Texas Forest Service, Lufkin, TX, pers. commun.).

Additional pests of loblolly pine on the study plots include the redheaded pine sawfly, Neodiprion lecontei, and the Nantucket pine tip moth (NPTM). Sawflies defoliated portions of the crown of loblolly pine. NPTM infestation rates were significantly higher on control loblolly pine than those treated with Terra-Sorb[R] (Table 2). These higher infestation rates led to increased multiple leaders and crooked boles in the control plots. Due to economic contraints, control of NPTM may not be practical on these sites.

Long-term effects of tip moth are difficult to assess, but include bole sweep and compression wood (Hedden and Nebeker 1984). Cade (1985) indicated tip moth damage is greater and lasts longer on poorly stocked or open grown stands.

Table 2. Nantucket pine tip moth infestation rates for four-year old loblolly pine, Typic Quartzipsamments soils.

| Treatment | Number of trees | Infestation Rate (mean $\pm$ SD)[1] |
|---|---|---|
| Untreated | 32 | 7.8% $\pm$ 7.8a |
| Clay Slurry | 56 | 5.8% $\pm$ 4.5ab |
| Terra-Sorb[R] | 77 | 5.1% $\pm$ 5.9b |
| All Trees Combined | 165 | 5.9% |

[1] Means followed by same letter not significantly different at P=.05 using Duncan's Multiple Range Test.

For loblolly pine, fourth-year leader length and total tree height were significantly greater for Terra-Sorb[R] and clay-slurry treated trees compared to control trees (Tables 3 and 4). During the 1986 growing season, 43 percent of the total height growth occurred for loblolly pine, compared over all treatments. Average height ranged from 148 cm for untreated loblolly to 181 and 190 cm for Terra-Sorb[R] and clay-slurry treated loblolly pine, respectively (Table 4).

Table 3. Fourth year leader length and percent total height, four year old loblolly pine, Typic Quartzipsamments soils.

| Treatment | Number of trees | Leader Length (cm)x $\pm$ SD[1] | Percent Total Height |
|---|---|---|---|
| Untreated | 32 | 60 $\pm$ 28 A | 40.5% |
| Clay Sturry | 56 | 91 $\pm$ 24 B | 47.9% |
| Terra-Sorb[R] | 77 | 85 $\pm$ 33 C | 47.0% |
| | 165 | 82 $\pm$ 31 | 43.1% |

[1]Means followed by same letter not significantly different at P=.05 using Duncan's multiple range test.

Table 4. Total tree height for four-year old loblolly pine, Typic Quartzipsamments soils.

| Treatment | Number of trees | Height (cm) (mean ± SD)[1] |
|---|---|---|
| Untreated | 32 | 148 ± 56a |
| Clay Slurry | 56 | 190 ± 51b |
| Terra-Sorb[R] | 77 | 181 ± 57b |
| All Trees Combined | 165 | 178 ± 56 |

[1] Means followed by same letter not significantly different at p =.05 using Duncan's Multiple Range Test.

Soil texture (Table 5) reflected the deep sand conditions (Dolezel 1980). Percent silt and clay combined, averaged less than eight percent for the top six centimeters measured over three sites. Longleaf pine, with 56 percent survival, was emerging from the grass stage. No brown spot needle blight, caused by Scirrhia acicola, was detected. Hazard rating for brown spot in this site is low as less than 50 percent of the stand is infected (Anderson et al. 1984).

On these droughty sites, stand disturbance during harvest cutting should be kept to a minimum. Containerized longleaf and Terra-Sorb[R]-treated loblolly pine had better survival (Table 1), but pest considerations (town ants and tip moths) reduce the usefulness of loblolly pine. To regenerate these sites, minimum exposure to drying winds to conserve soil moisture and to reduce decomposition of humus and organic remains (Wilde 1948, 1958) is recommended.

Table 5. Texture analyses of planting sites TN-1 (planted Jan. 83), TN-2 (planted Jan. 85, and an undisturbed natural stand (TN-3), a Typic Quartzipsamment.

| Sampling Depth (cm) | TN-1 % sand | TN-1 % silt | TN-1 % clay | TN-2 % sand | TN-2 % silt | TN-2 % clay | TN-3 % sand | TN-3 % silt | TN-3 % clay |
|---|---|---|---|---|---|---|---|---|---|
| 0 - 6 | 92.0 | 4.5 | 3.5 | 91.0 | 4.7 | 4.3 | 92.1 | 5.1 | 2.8 |
| 30 - 38 | 94.1 | 3.6 | 2.3 | 91.8 | 3.9 | 4.3 | 92.5 | 4.4 | 3.1 |
| 61 - 69 | 95.0 | 3.2 | 1.8 | 92.5 | 3.8 | 4.2 | 92.6 | 4.4 | 3.0 |
| 91 - 99 | 96.0 | 2.6 | 1.4 | 92.6 | 3.6 | 4.7 | 92.5 | 4.6 | 2.9 |
| 122 - 130 | 96.1 | 2.6 | 1.3 | 92.5 | 3.8 | 4.4 | 92.7 | 4.4 | 2.9 |
| 152 - 160 | 96.2 | 2.7 | 1.1 | 92.7 | 3.8 | 4.4 | 93.4 | 4.3 | 2.3 |
| Average | 94.9 | 3.2 | 1.9 | 91.7 | 3.9 | 4.4 | 92.7 | 4.5 | 2.8 |

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# Vegetative Management

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# RELATIONSHIPS AMONG FIRST-YEAR LOBLOLLY PINE SEEDLING PERFORMANCE, VEGETATION REGROWTH, ENVIRONMENTAL CONDITIONS AND PLANTATION MANAGEMENT PRACTICES[1]

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Abstract.--Performance of loblolly pine (Pinus taeda L.) seedlings, regrowth of natural vegetation and environmental conditions were monitored during the first growing season of an experimental plantation established on a recently clearcut site in the Piedmont of North Carolina. High and low intensities of both site preparation (shearing, piling and double-disking versus chopping) and cultural practice (herbicide versus no herbicide) were applied in a factorial to create four treatment combinations. Chopping left significantly more leaf and wood litter on the soil surface than did shear-pile-disk; both radiant energy at the litter surface and maximum soil temperature were higher in shear-pile-disk. Chopping favored the regeneration of vines and trees from intact root systems and the establishment of grasses, whereas the shear-pile-disk treatment resulted in a community derived from seed and composed largely of early successional forbs. Although site preparation had no significant effect on pine growth in the first year, an observed trend toward better performance in shear-pile-disk relative to chopping was confirmed in the following year. Herbicide application had modest effects on the regrowth of natural vegetation. However, this treatment increased the radiant energy and, in shear-pile-disk, increased the availability of nitrate. Height growth of pines was slower and diameter growth more rapid in plots treated with herbicide. Height growth of pines was positively correlated with soil ammonium concentration, and negatively correlated with the cover of wood and leaf litter and with the volume of vines and canopy trees, factors which could have contributed to a reduction in ammonium pools. Diameter growth of pines was positively correlated with reduced regrowth of natural vegetation and greater nitrogen availability.

Keywords: Competition, site preparation, herbicide, Pinus taeda L.

## INTRODUCTION

Several studies have established that vegetation regrowth on recently clearcut sites reduces nutrient losses caused by increased leaching and erosion, increased decomposition, and decreased plant uptake (Bormann and Likens 1979; Boring and others 1981; Cox and Van Lear 1985). Vegetation regrowth, however, may also interfere with performance of pine seedlings in plantations. A number of investigators have demonstrated that pine growth can be significantly increased by reducing hardwood competition (Freeman and Van Lear 1977; Sterrett and Adams 1977; Clason 1978; Cain and Mann 1980; Carter and others 1984). Herbaceous plants have also been implicated as competitors of pine seedlings in areas supporting a small proportion of woody regrowth (Schultz 1976; Nelson and others 1981; Carter and others 1984).

The effect of various site preparation methods on the pine-vegetation interaction is poorly understood. Schultz (1976) indicated that intensive site preparation in Florida flatwoods could improve first-year tree survival by reducing vegetative competition for light, water, and nutrients. Haines and Pritchett (1965), however, suggested that the effect of intensive site preparation on nutrient availability in these lowland areas could be more important than vegetation regrowth in determining pine growth.

The paucity of investigations which quantify both the abiotic environment and vegetation regrowth in relation to early pine performance under various forest management practices provided motivation for the research described in this paper. Our objective was to study, in a nondestructive and quantitative fashion, the performance of loblolly pine (Pinus taeda L.) seedlings in relation to their immediate environment under the influence of high and low intensity site preparation and cultural treatments in the North Carolina Piedmont. To better understand how forest management affected the pine-vegetation interaction, we took a two-fold approach of: (1) assessing the effects of the treatments on vegetation regrowth, the abiotic environment, and pine growth; and (2) determining which growth forms and environmental factors were most closely associated with pine growth. This paper examines the first year's results of the study.

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## METHODS

### Study Site and Experimental Design

The study was established following clear-felling in February 1981 of a 22-year-old second rotation loblolly pine stand as part of the Site Productivity Study being conducted by the North Carolina State University Southern Forest Research Center. The stand was located on land owned by Champion International Corporation in the north-eastern North Carolina Piedmont (Vance County) on soils which belong to the Cecil series (clayey, kaolinitic, thermic, Typic Hapludult).

The experiment involved four treatments derived from a factorial of two site preparation intensities and two levels of herbicide treatment. The low intensity site preparation consisted of one pass of a heavy drum chopper (treatment referred to hereafter as CH). In the high intensity site preparation, stems which remained on the site after harvest were sheared at ground level, organic debris was piled into windows, and the site was subsequently disked (DI). Velpar® gridballs (hexazinone) were applied at a rate of 10 kg/ha for the high intensity herbicide treatment (H+). No herbicide was applied in the low intensity herbicide treatment (H-). The four treatment combinations (CHH-, CHH+, DIH-, DIH+) were arranged in a split-plot design within each of three blocks; site preparation treatments were assigned to whole-plots and herbicide treatments were assigned to split-plots. A 15 x 30 m measurement plot was established within each of the 12 block-treatment areas.

Site preparation was carried out in July 1981. The site was hand planted with improved nursery stock of one year old loblolly pine seedlings on a 2x3 m spacing in March 1982. Herbicide was applied in May 1982.

### Assessment of Vegetation Regrowth

Four pine seedlings were randomly selected within each measurement plot. For each pine, a 3 x 2 m subplot was positioned such that the pine seedling was located at the center of the plot. In August 1982, vegetation regrowth surrounding the pines was assessed by recording the species, approximate outline shape (i.e., common geometric solids such as cone, ellipsoid, etc.) and appropriate outline dimensions for each plant or plant part located within 1 m of the central pine. Plant dimensions were used to calculate the above-ground space occupied by each individual, hereafter referred to as volume. All species were classified as belonging to one of seven growth-forms: forb, grass, sedge/rush, vine, shrub, understory tree, canopy tree. Growth form classes were chosen to reflect differing ecological behaviors of species within a community. For example, understory trees can be distinguished from canopy trees by their slower growth rates and greater shade tolerance.

### Assessment of Environmental Conditions

Integrating light meters, constructed from booklets of photosensitive diazo paper (Francis 1970), were used to obtain an estimate of the amount of radiant energy reaching the forest floor of each subplot, relative to that which reached an area within the study site lacking vegetation and slash. Four light meters per subplot were set out before dawn on a mostly sunny day in August, and retrieved at dusk.

Maximum-minimum thermometers were inserted in the soil to a depth of 15 cm at the edge of each subplot in late July, and were monitored for maximum and minimum temperatures every two weeks thereafter. Percentage cover for both wood and leaf litter located within 1 m of the pine were visually estimated in each subplot during May 1982. Information on percentage soil moisture, and soil ammonium and nitrate concentrations for each measurement plot were provided by P.M. Vitousek (personal communication). Soil samples for these measurements were taken to a depth of 15 cm in June, July, and August 1982. Percentage soil moisture was determined gravimetrically; ammonium and nitrate concentrations were assessed via KCl extraction and colorimetric determination on an autoanalyzer.

### Assessment of Loblolly Pine Growth

The height and root collar diameter of the central pine within each of the 48 subplots were measured in May and October 1982 to determine the rate of growth for each pine during the growing season.

### Calculations and Analyses

The volumes for all individual plants within a growth form class were summed to obtain a growth form volume per ground area for each subplot. For each growth form class, growth form volume was also expressed as a percentage of total subplot volume. Averages over subplots within measurement plots were used in the analyses.

Means over the growing season were calculated for all soil variables, since treatment responses were parallel over the time span indicated. Both maximum and minimum temperatures were averaged over a two month period (late July to late September), while soil moisture, and ammonium and nitrate concentrations, were averaged over the three month period extending from June through August.

Relative growth rates were used as pine height and diameter growth variables to reduce the influence of initial size on the analyses. These relative growth rates were calculated for each pine using the following equation (Evans 1972):

relative growth rate =

$$\frac{\ln(\text{October measurement}) - \ln(\text{initial measurement})}{(\text{time } 2 - \text{time } 1)}$$

where (time 2 - time 1) represented the entire growing season and was considered equivalent to 1.

Treatment effects on vegetation regrowth, environmental conditions, and loblolly pine growth were tested using ANOVAs and Fishers's protected lsd tests. Correlation coefficients among August vegetation volumes, environmental parameters, and pine relative growth rates were used to detect possible relationships.

A principal components analysis biplot (Gabriel 1971), using August growth-form volumes as attributes of the measurement plots, was employed to further investigate the relationships between treatments and vegetation regrowth. In prinicpal components analysis the original data space, in this case measurement plot points located within the seven dimensional space defined by the growth-form volume axes, is redefined irrespective of the original axes such that the first new axis (called a component) accounts for the maximum amount of variation present in the measurement plot points. Subsequent components are sequentially determined such that each accounts for the maximum amount of the remaining variation and is orthogonal to the previous components. Each component is a linear combination of the original axes, and the first two or three components can be used to summarize a large proportion of the variation in the data. The biplot aspect of this analysis refers to a representation of the original axes (growth-form vectors in Figure 1) as projected onto the two dimensional space defined by two components. The degree to which a given component is correlated with one of the original axes can be determined from the relative length of the growth-form vector's projection onto that component.

For example, in Figure 1, the first component is positively correlated with forbs and negatively correlated with grasses, but has little association with understory trees. Likewise, measurement plots which have a high positive score on the first component have relatively large volumes of forbs and relatively small volumes of grasses.

All statistical analyses, excepting the biplot, were performed using Statistical Analysis System procedures (SAS Institute, Inc. 1982). Results reported were significant at $p<=.05$ unless otherwise indicated. Since vegetation regrowth was quite variable, p-values less than .10 were reported for some of these results and should be interpreted as indicative of potential trends.

## RESULTS

### Effects of Treatments on Vegetation Regrowth

Significantly larger volumes of grasses (e.g., *Panicum* spp.) and canopy trees (e.g., *Quercus* spp., *Liriodendron tulipifera* L., *Acer rubrum* L.) were present in CH sites than in DI sites (Tables 1 and 2). Canopy trees also made up a larger proportion of the total vegetation volume in CH relative to DI plots, whereas forbs contributed significantly more to total vegetation volume in DI sites. Most of the forbs (e.g., *Aster* spp., *Erigeron* spp., *Verbascum thapsus* L.) were early successional species; few herbaceous species present in the adjacent forest were found in subplots.

Vines (e.g., *Lonicera* spp., *Parthenocissus quinquefolia* L., *Vitis* spp.) contributed more toward total vegetation volume in the H- plots ($p=.06$), while canopy trees performed better (in terms of both absolute volume and percentage of total volume ($p=.07$)) in the H+ plots. The greater volume of canopy trees in H+ and, in particular, CHH+ plots was unexpected and apparently existed prior to herbicide application. An ANOVA on May 1982 canopy tree volumes (unpublished data) collected prior to herbicide damage suggested these pretreatment differences, and an analysis of canopy tree relative growth rates revealed no significant main effects or interactions involving cultural treatments.

There was an interaction between site preparation and herbicide treatment for volume of vines ($p=.06$) expressed as a percentage of total vegetation volume. The proportion of vine volume was greater in CHH- than in CHH+ plots, and both CH treatments had greater vine volume relative to total vegetation than did DI treatments. A similar interaction was observed for absolute volume of canopy trees; the volume was greater in CHH+ than in CHH- plots, and both CH treatments had greater canopy tree volume than did DI treatments.

The first two axes of the biplot accounted for 60.4 percent of the variation in the data, with 36.4 percent and 24.0 percent accounted for by components 1 and 2, respectively. The biplot showed a clear separation between CH and DI plots along the first axis (Figure 1). Growth-form vectors indicated that CH plots were consistently associated with greater grass, canopy tree, and, to a lesser extent, sedge volumes. DI plots were consistently associated with greater volume of forbs. There was considerable within-treatment compositional variation for site preparation treatments, particularly for the CH treatment.

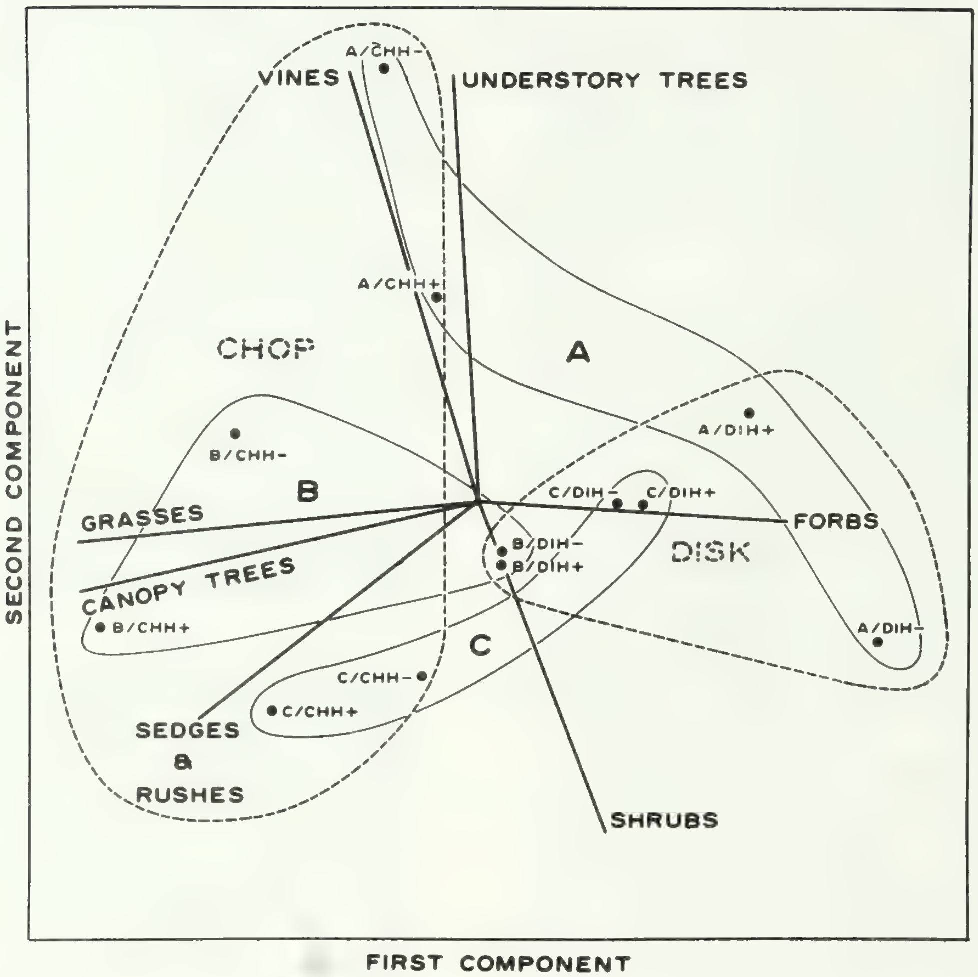


FIGURE 1. Locations of 12 measurement plots relative to the first 2 components of a principal components analysis using growth-form volumes as plot attributes. Outlines indicate membership of plots in blocks (solid lines) and site preparation treatments (dashed lines); cultural treatments are indicated by the notations H+ (herbicide) and H- (no herbicide). See text for interpretation of plot.

TABLE 1. Significant treatment effects on growth form, environment, and pine growth variables.[a]

| Dependent Variable | Treatment[b]: Site Preparation | Cultural | Site Preparation x Cultural |
|---|---|---|---|
| Forbs (percent total volume) | DI > CH (*) | | |
| Grasses (absolute volume) | CH > DI (*) | | |
| Vines (percent total volume) | | H- > H+ (p=.06) | CHH- > CHH+ > DIH- = DIH+ (p=.06) |
| Canopy trees (absolute volume) | CH > DI (*) | H+ > H- (*) | CHH+ > CHH- > DIH- = DIH+ (*) |
| (percent total volume) | CH > DI (*) | H+ > H- (p=.07) | |
| Light | DI > CH (*) | H+ > H- (*) | |
| Wood litter | CH > DI (*) | | |
| Leaf litter | CH > DI (**) | | |
| Maximum soil temperature | DI > CH (*) | | |
| Soil nitrate concentration | | | DIH+ > DIH- = CHH- = CHH+ (*) |
| Pine height growth rate | | H- > H+ (*) | |
| Pine diameter growth rate | | H+ > H- (*) | |

[a]Treatment differences assessed by Fisher's protected lsd test.
Significance levels: * = $p \leq .05$, ** = $p \leq .01$, *** = $p \leq .001$.

[b]Treatment symbols: DI = disk, CH = chop, H+ = herbicide, H- = no herbicide, CHH- = chop-no herbicide, CHH+ = chop-herbicide, DIH- = disk-no herbicide, DIH+ = disk-herbicide.

TABLE 2. Absolute vegetation volume and percentage of total vegetation by treatment combination for seven growth-forms (means over blocks ± standard errors, N=3).

| | Treatment Combinations[a]: CHH- Absolute[b] | CHH- Percent[c] | CHH+ Absolute | CHH+ Percent | DIH- Absolute | DIH- Percent | DIH+ Absolute | DIH+ Percent |
|---|---|---|---|---|---|---|---|---|
| Forbs | 41.0 ± 8.2 | 15.7 ± 4.9 | 39.4 ± 12.5 | 14.6 ± 5.9 | 96.3 ± 68.3 | 48.9 ± 9.4 | 55.8 ± 41.5 | 48.3 ± 18.7 |
| Grasses | 43.3 ± 13.0 | 15.5 ± 4.3 | 40.5 ± 14.1 | 13.9 ± 4.5 | 13.2 ± 7.7 | 16.1 ± 8.1 | 7.9 ± 4.3 | 13.1 ± 7.2 |
| Sedges and rushes | 0.5 ± 0.2 | 0.2 ± 0.1 | 1.1 ± 0.5 | 0.4 ± 0.2 | 0.4 ± 0.1 | 0.4 ± 0.2 | 0.4 ± 0.3 | 0.6 ± 0.6 |
| Vines | 21.8 ± 8.0 | 9.1 ± 4.5 | 14.7 ± 11.6 | 5.9 ± 4.8 | 2.4 ± 2.3 | 0.7 ± 0.6 | 0.6 ± 0.3 | 0.7 ± 0.4 |
| Shrubs | 45.8 ± 39.9 | 13.4 ± 11.1 | 28.9 ± 21.9 | 9.2 ± 6.8 | 51.6 ± 42.2 | 20.6 ± 7.6 | 12.3 ± 2.8 | 23.6 ± 13.8 |
| Understory trees | 5.6 ± 5.6 | 2.7 ± 2.7 | 0.7 ± 0.3 | 0.2 ± 0.1 | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.8 ± 1.8 | 1.1 ± 1.1 |
| Canopy trees | 124.1 ± 28.2 | 43.5 ± 7.2 | 162.5 ± 22.8 | 55.9 ± 4.1 | 11.2 ± 8.7 | 13.2 ± 8.2 | 7.1 ± 4.6 | 12.6 ± 7.3 |
| Total Vegetation | 282.0 ± 42.5 | | 287.9 ± 22.7 | | 175.1 ± 102.9 | | 85.9 ± 38.8 | |

[a]Treatment symbols as in Table 1.

[b]Vegetation volume (1000 $cm^3/m^2$ ground area).

[c]Percentage of total vegetation volume.

Block separation was evident in the biplot (Figure 1), primarily on the second component. Greater volumes of forbs, vines, and understory trees were present in block A than in other blocks, whereas block B tended to have greater grass, canopy tree, and sedge volumes. Block C's position in the biplot reflected a greater volume of shrubs, but was to some extent intermediate to the positions of blocks A and B.

Herbicide treatments appeared to be compositionally similar since the H+ and H- treatments for each block-site preparation combination were relatively close to one another. This similarity was particularly evident in the DI site preparation treatment. Overall, the effects of site preparation and blocking on composition were more pronounced than those of herbicide treatment.

## Effects of Treatments on Environmental Conditions

Site preparation had a significant effect on the amount of litter left on the sites, with cover of both leaf and wood litter in CH plots higher than that found in DI plots (Tables 1 and 3). Maximum soil temperatures and the amount of light energy reaching the forest floor were greater in DI than in CH sites. H+ plots also received greater radiant energy relative to H- plots. There was a significant interaction between site preparation and herbicide treatment for soil nitrate concentrations, with concentrations higher in DIH+ plots than in plots receiving all other treatments.

## Effects of Treatments on Loblolly Pine Relative Growth Rates

Herbicide treatments had a significant effect on both height and root collar diameter growth rates (Tables 1 and 4). Diameter growth rates were significantly higher in H+ plots, whereas height growth rates were higher in H- plots. Site preparation did not significantly affect either height or diameter growth.

## Associations Between Vegetation Regrowth, Environmental Conditions, and Loblolly Pine Relative Growth Rates

Height growth was negatively correlated with August vine and canopy tree volume and both leaf and wood litter, and positively correlated with soil ammonium concentration (Table 5). Root collar diameter was negatively correlated with vine volume and wood litter, and positively correlated with light, maximum soil temperature, and both soil ammonium and nitrate concentrations. Pine height and root collar diameter growth were not significantly correlated with one another. Significant correlations occurred frequently both among environmental variables and between vegetation and environmental variables (Table 5).

# DISCUSSION

## Effects of Treatments on Vegetation Regrowth

The separation of CH and DI sites along the first principal component (Figure 1) suggested that site preparation was the most important factor influencing composition of vegetation in this experiment. Chopping caused minimal damage to stumps and roots, and favored regeneration of growth forms (such as trees and vines) which were capable of sprouting rapidly and taking advantage of large root system reserves plus the enhanced availability of light and below-ground resources following harvest (Thomas 1980; Borman and Likens 1979; Vitousek and Matson 1984). In DI plots, where sprouting was restricted by damage to and removal of most root systems during site preparation, seed regeneration was favored. The high light intensities and increased temperature fluctuations required for germination of most early successional forbs (Grime and Jarvis 1975; Grime 1979) and the scarcity of individuals from the more vigorous growth forms probably aided in the establishment of these poor competitors.

The dichotomy of sprouting versus seed regeneration between site preparation techniques was not complete. Factors such as stratification of the seedbank and physiological limitations also may have influenced the composition of vegetation regrowth. For example, in Fall 1981 the recently prepared CH sites supported a dense seed-borne population of fireweed (Erechtites hieracifolia L.), which did not appear in the more deeply scraped DI areas until the following year as progeny from the CH populations. Another exception was seen with grasses. Germination of grasses was plentiful in both CH and DI plots, but DI individuals rarely achieved the size of those in CH plots. This differential growth could have resulted from the limitations placed upon the net photosynthesis of these predominantly $C_3$ species by photorespiration in the high light and high temperature environment of the DI plots (Smith and Brown 1973, Ehleringer 1978).

The second axis of the biplot revealed the importance of site specific factors in vegetation regrowth (Figure 1). For example, more vigorous regrowth was observed in block A-DI plots and was most likely enhanced by the higher initial fertility of block A relative to blocks B and C (L.A. Morris, P.M. Vitousek, unpublished data), and the moister conditions resulting from its low topographic position (mean percent soil moisture and standard errors for DI plots within blocks A, B, and C, respectively: $27.7 \pm 1.2$, $16.9 \pm 2.0$, $20.4 \pm 1.3$). The larger buried seed pools which have been observed in more fertile sites (Hill 1979) also may have contributed to the sharp contrast in DI regrowth across blocks.

TABLE 3. Means over blocks ( ± standard errors, N=3) for environmental variables by treatment combination.

| | Treatment Combinations[a] | | | |
|---|---|---|---|---|
| | CHH- | CHH+ | DIH- | DIH+ |
| Light[b] | 15.1 ± 0.1 | 24.8 ± 4.0 | 29.8 ± 6.0 | 36.4 ± 3.8 |
| Wood Litter (percent cover) | 11.4 ± 1.4 | 10.3 ± 1.6 | 2.3 ± 0.7 | 2.9 ± 0.3 |
| Leaf Litter (percent cover) | 93.0 ± 1.8 | 96.8 ± 0.6 | 17.6 ± 3.9 | 12.8 ± 4.3 |
| Maximum temperature ($^{o}$C) | 27.9 ± 0.1 | 28.0 ± 0.2 | 29.6 ± 0.4 | 30.4 ± 0.1 |
| Minimum temperature ($^{o}$C) | 20.7 ± 0.1 | 20.5 ± 0.2 | 20.7 ± 0.3 | 20.3 ± 0.3 |
| Soil Moisture (percent dry weight) | 23.0 ± 1.1 | 22.0 ± 1.5 | 22.6 ± 3.4 | 20.8 ± 3.5 |
| Soil Ammonium (ppm) | 3.3 ± 0.4 | 3.3 ± 0.3 | 4.1 ± 0.8 | 5.7 ± 1.2 |
| Soil Nitrate (ppm) | 0.0 ± 0.0 | 0.0 ± 0.0 | 3.9 ± 2.4 | 10.9 ± 2.6 |

[a] Treatment symbols as in Table 1.

[b] Radiant energy measured by a diazo paper light meter, expressed as a percentage of that measured by an unshaded control.

TABLE 4. Means over blocks ( ± standard errors, N=3) for loblolly pine relative growth rates in the 1982 growing season by treatment combination.

| | Treatment Combinations[a] | | | |
|---|---|---|---|---|
| | CHH- | CHH+ | DIH- | DIH+ |
| Height | 1.04 ± 0.13 | 0.75 ± 0.09 | 1.24 ± 0.04 | 1.18 ± 0.10 |
| Root Collar Diameter | 0.26 ± 0.06 | 0.38 ± 0.11 | 0.37 ± 0.05 | 0.65 ± 0.03 |

[a] Treatment symbols as in Table 1.

TABLE 5. Correlation coefficients between loblolly pine relative growth rates, vegetation volumes and environmental conditions.[a]

| | Vegetation Volume | | | Environment | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Vines | Canopy Trees | Total Vegetation | Light | Wood Litter | Leaf Litter | Maximum Temperature | Soil Ammonium | Soil Nitrate |
| PINE RELATIVE GROWTH RATES | | | | | | | | | |
| Height | -.63(*) | -.63(*) | -.18 | .31 | -.74(**) | -.66(*) | .54 | .59(*) | .49 |
| Root Collar diameter | -.68(*) | -.42 | -.51 | .72(**) | -.65(*) | -.55 | .69(*) | .65(*) | .74(**) |
| ENVIRONMENT | | | | | | | | | |
| Light | -.63(*) | -.54 | -.71(**) | | -.63(*) | -.63(*) | .84(***) | .54 | .82(**) |
| Wood Litter | .77(**) | .80(*) | .47 | | | .93(***) | -.80(**) | -.55 | -.61(*) |
| Leaf Litter | .60(*) | .92(***) | .62(*) | | | | -.91(***) | -.53 | -.70(*) |
| Maximum Soil Temperature | -.58(*) | -.85(***) | -.82(**) | | | | | .63(*) | .89(***) |
| Soil Ammonium | -.45 | -.55 | -.43 | | | | | | .72(**) |
| Soil Nitrate | -.52 | -.68(*) | -.79(**) | | | | | | |

[a]Significance levels: * = $\leq$ .05, ** = $p \leq .01$, *** = $p \leq .001$.

Herbicide application had only moderate influence on vegetation regrowth during 1982. Field observations revealed local damage (apparently where Velpar® gridballs were placed), but total reduction in vegetation was small and limited primarily to vines (Table 2). Vines may have been particularly susceptible to Velpar® damage because their creeping habit would have increased the probability of encountering soil contaminated with the systemic herbicide.

## Effects of Treatments on Environmental Conditions

Site preparation effects on environmental conditions observed in this study were consistent with those of other investigations (Haines and others 1975; Schultz 1976). The large quantities of organic matter which were removed under the high intensity site preparation treatment left little wood or leaf litter on the soil surface. The increased light energy reaching the soil surface in DI sites was a direct result of the sparser foliage. The increased light energy coupled with reduced insulation by surface litter probably led to higher maximum soil temperature in DI than in CH plots.

Herbicide application produced little effect on most environmental conditions, probably because of the failure of Velpar® to significantly alter vegetation regrowth in 1982. The increased light energy in H+ plots, however, was most likely a result of the slight reduction which did occur in most growth-form classes as a result of herbicide damage.

The elevated concentrations of nitrate in DIH+ plots relative to all other treatments was found to be largely a product of reduced immobilization (via microbial uptake) caused by the removal of organic residues (Vitousek and Matson 1984).

## Loblolly Pine Growth in Relation to Vegetation Regrowth, Environmental Conditions and Forest Management

Research on competitive interactions points to the importance of rapid early growth in the attainment of dominance within a community (Ross and Harper 1972; Harper 1977). Enhanced growth may be facilitated by an increase in the availability of resources and/or a reduction in harmful competitors. Among the resources monitored in this investigation, greater pine growth rates appeared to be associated with increased ammonium concentrations. Factors which can adversely affect nitrogen availability, such as increased quantities of wood and leaf litter, were negatively associated with improved pine performance. In experiments conducted at the same site, Vitousek and Matson (1984 and personal communication) found that immobilization of nitrogen in organic matter was primarily responsible for reduced ammonium (and hence nitrate) availability. Since the plantation was probably nitrogen-limited prior to harvest (Allen and Ballard 1983), it is possible that incorporation of nitrogen into microbial biomass may have limited pine seedling growth.

The positive correlation between root collar diameter growth rates and radiant energy may have occurred via several pathways. The increase in solar energy associated with a decline in vegetation volume may actually have encouraged diameter growth (root collar diameter and crown relative growth rates: r=.70, unpublished data); in the absence of direct shading by neighboring vegetation, energy that would have been devoted to height growth may have been allocated to diameter growth, thereby enhancing light harvesting abilities for the pines. Furthermore, an increase in radiant energy may have indirectly affected nitrogen availability and root metabolism by elevating soil temperatures (Helms 1976).

Although studies have indicated that soil moisture can be an important factor in pine performance (Sterrett and Adams 1977; Stone 1980; Nelson and others 1981), moisture conditions were favorable during the 1982 growing season, and hence did not appear to be correlated with pine growth. Examination of 1983 data, however, has indicated that moisture was a significant factor in pine growth under the drought conditions which prevailed over much of that growing season (Byrne and others, in press).

Early pine growth was also enhanced by reduced volumes of competitive growth forms such as vines and trees. The well distributed root systems of vines could have increased the probability of direct below-ground interference with the pines, while allowing the vines access to a greater volume of soil as an alternative to the local resource depletion which may have resulted from this interference. Although direct shading of pine seedlings by vines was not observed, light is known to stimulate vine growth in disturbed habitats (Thomas 1980). The rapid growth rates conferred to vines by their efficient capture and use of light (Wechsler 1977), and their ability to compete below-ground with other early successional and established individuals (Boring and others 1981; Whigham 1984) indicate the competitive potential of this growth-form. Although the relatively intact root systems of trees probably provided them competitive advantages similar of those of vines, canopy trees may also have been indirectly related to nitrogen availability by their inherent association with residual slash following harvest and low-intensity site preparation.

Under the conditions of this experiment, the shear-pile-disk sequence achieved favorable conditions for first-year pine growth through reduction in vegetation volume (on drier sites, blocks B and C), selection against strong competitors, and an increase in light and nitrogen availability. Although the enhanced resource availability and reduction in competition did not cause statistically significant differences in pine growth, both root collar diameter growth and, in particular, height growth exhibited a tendency toward greater rates in DI

plots. This trend was confirmed by 1983 data (S.V. Byrne, personal communication). Herbicide application caused only a slight and insignificant reduction in competing vegetation, but it was enough to significantly increase the availabilty of light and, in DI plots, nitrate, thereby accelerating root collar diameter growth. Although it is not obvious which direction of expansion is more favorable, early rapid diameter growth may result in faster canopy closure and thus earlier dominance of the site.

It should be noted that these results do not necessarily foreshadow trends in long term productivity; several studies have shown that pine performance may decline on more intensively prepared sites over time (Keeves 1966; Whyte 1973). However, intensive study of early pine performance in relation to the surrounding biotic and abiotic environment is useful for developing hypotheses concerning competitive interactions and, in the long run, the ecological mechanisms involved in the early phases of plantation development.

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# IMPACT OF INTENSIVE COMPETITION MANAGEMENT ON DOMINANT STAND HEIGHT [1/]

G. Daniel Ayers, Terry R. Clason, and William D. Smith [2/]

Abstract.--One loblolly pine spacing study and three vegetative management studies were used to evaluate the impact of intra-specific and inter-specific competition on dominant stand height. The pine spacing study exhibited a strong dominant height-pine density relationship from ages 13 to 33. Dominant height at age 33 was 16 feet greater in the widest spacing than in the narrowest spacing. Yield estimation biases had an absolute range of 26.5 percent when the dominant height-density relationship was ignored. This translated to total volume (i.b.) bias ranging from 468 $ft^3$ per acre under-estimation to 528 $ft^3$ per acre over-estimation. All vegetation management studies revealed a significant response to hardwood and herbaceous vegetation control. Total vegetation control elicited the greatest reponse in dominant height.

## INTRODUCTION

Dominant height (DH) is more closely related to the wood producing capacity of a timber site than any other single stand measure. It is also the stand measure least affected by sivlicultural practices. Consequently, dominant stand height is the foundation for our present day site index (SI) model. SI, in turn, is the driving variable for most contemporary growth and yield models.

Height as a site classification tool has been used, at least in Germany, since 1908 (Roth 1916). Height classes ranged from 3 to 5 and differences between classes were generally greater than 10 feet. In the southern U.S., 10-feet SI classes based on dominant height have been use in growth and yield prediction (Shumacher and Coile 1960). Although DH is the stand variable least affected by silvicultural treatments, these treatments do elicit some response. When do these reponses significantly affect site classification and growth and yield predicition?

Lloyd and Jones (1982) found a significant relationship between DH and pine density. They also demonstrated that prediction biases were significant and cumulative over time when the DH-density relationship was ignored in growth estimation. Although much research has been directed towards quantifying effects of hardwood and herbaceous competition on pine stand development, specific effects on DH have not been reported. Because pine density (intra-specific competition) significantly affects DH, hardwood and herbaceous (inter-specific) competition should cause similar responses.

The objectives of the following analyses were: to support the existence of a significant DH-pine density relationship; to demonstrate that ignoring this relationship can result in considerable yield prediction bias; and to show that a significant relationship between DH and inter-specific competition exists at an early age.

## EXPERIMENTAL DATA

Because DH and site quality are so closely related, DH responses to intra-specific and inter-specific competition can be difficult to isolate. Spacing and vegetative management experiments with randomized complete block designs and uniform within-block site characteristics are necessary for this purpose.

## DOMINANT HEIGHT AND INTRA-SPECIFIC COMPETITION

The DH-pine density relationship was examined using a 37-year-old loblolly pine spacing study located at the Hill Farm Research

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Station in Homer, LA. Spacing treatments were 4x4, 6x6, 6x8, 8x8, and 10x10 feet. The 10x10 spacing treatment had one replication, while the other treatments were replicated twice. DH was defined as the average height of the tallest 40 percent of the standing trees in each plot.

Stocking was defined for each spacing at age 13, 18, 21, 22, 25, 28, 29, and 33 (Table 1). Mortality was highest in the 4x4 spacings. Generally, mortality decreased with increased spacing. From age 13 to 25, mortalities for the 4x4, 6x6, 6x8, 8x8, and 10x10 treatments were 45, 27, 25, 12, and 9 percent, respectively. From age 25 to 33, mortalities increased for the respective spacings to 50, 45, 27, 42, and 22 percent.

DH for each measurement age and spacing is summarized in Table 2. We assumed that the relationships evident in this table were due to density effects on DH and not on differences in site quality. Our data support this assumption. If site quality was significantly different among treatments, we would expect greater irregularity in responses from the various treatments before age 10. This was not evident. Height growth, as measured by average height of the 100 largest diameter trees per acre (top height), was close across spacings until age 10. By age 10, intra-specific competition was well advanced in the 4x4 treatments and the wider spacings had markedly higher top heights. At age 9, top height was 28.0, 29.9, 28.3, 29.2, and 29.4 feet for the 4x4, 6x6, 6x8, 8x8, and 10x10 spacings, respectively. By age 10, top height was 30.8, 33.7, 32.2, 34.0, and 33.9 feet for the respective treatments.

Analysis of variance (ANOV) of DH of the various treatments was generally not significant ($p \leq 0.05$), although $r^2$ values were greater than 0.80, except for age 25 which exhibited an $r^2$ of 0.70. However, least significant difference (LSD) mean comparisons and orthogonal polynomial contrasts revealed some consistent differences. In all years, LSD comparisons detected significant differences between the 4x4 and 10x10 spacings. LSD groupings did not differentiate between the 4x4, 6x6, 6x8, and 8x8 spacings, but orthogonal contrasts revealed a significant difference between the 4x4 spacing and the combined average of all other spacings. The 6x6, 6x8, and 8x8 spacings were never signifcantly different. From age 18 to age 33, the 10x10 spacing exhibited a DH at least 6.5 feet greater than all other spacings. Although these differences were large, LSD and orthogonal contrasts detected no significant differences among the 6x6, 6x8, 8x8, and 10x10 spacings. It is important to note that height advantages achieved at an early age were maintained to age 33.

Table 1.--Number of trees per acre by spacing and age. 1/

| | Planting spacing (ft x ft) | | | | |
|---|---|---|---|---|---|
| Age | 4x4 | 6x6 | 6x8 | 8x8 | 10x10 |
| | Trees per acre | | | | |
| 13 | 1730 | 856 | 672 | 587 | 383 |
| 18 | 1658 | 854 | 672 | 581 | 383 |
| 21 | 1366 | 775 | 620 | 541 | 371 |
| 22 | 1232 | 752 | 590 | 532 | 359 |
| 25 | 948 | 626 | 502 | 516 | 347 |
| 28 | 723 | 550 | 441 | 486 | 323 |
| 29 | 676 | 526 | 438 | 470 | 299 |
| 33 | 472 | 345 | 366 | 299 | 269 |

1/ Values shown are averages of two blocks except for the 10x10 spacing with one replication.

Table 2.--Mean total height of the tallest 40 percent of plot trees by spacing and age. 1/

| | Planting spacing (ft x ft) | | | | |
|---|---|---|---|---|---|
| Age | 4x4 | 6x6 | 6x8 | 8x8 | 10x10 |
| | Height (ft) | | | | |
| 13 | 38.7 | 41.0 | 40.9 | 42.2 | 44.3 |
| 18 | 48.8 | 50.8 | 51.0 | 51.4 | 58.6 |
| 21 | 55.2 | 60.0 | 60.0 | 60.2 | 66.8 |
| 22 | 56.2 | 60.7 | 60.9 | 61.0 | 69.6 |
| 25 | 63.2 | 68.9 | 68.6 | 67.2 | 76.9 |
| 28 | 64.8 | 71.2 | 71.8 | 70.4 | 79.7 |
| 29 | 68.0 | 73.9 | 73.9 | 71.8 | 82.3 |
| 33 | 70.8 | 78.6 | 80.2 | 76.7 | 87.2 |

1/ Values shown are averages of two blocks except for the 10x10 spacing with one replication.

The results of linear regressions of the natural logarithm of DH as the dependent variable, and the inverse of the number of trees per acre as the independent variable, are shown in Table 3. $R^2$ values ranged from 0.56 to 0.82. All regressions were highly significant ($p \leq 0.01$) except for age 33. The regression model and slope parameter for age 33 was significant at the 0.05 level.

Table 3.--Linear regression models and $r^2$ values for predicting the natural log of dominant height from the inverse of the number of trees per acre.

| Age | Intercept | Slope | $r^2$ |
|---|---|---|---|
| 13 1/ | 3.61868 | 69.97657 | 0.73 |
| 18 1/ | 3.82256 | 82.33115 | 0.56 |
| 21 1/ | 3.93965 | 95.01748 | 0.66 |
| 22 1/ | 3.93965 | 104.28399 | 0.73 |
| 25 1/ | 4.02833 | 105.74684 | 0.67 |
| 28 1/ | 4.03314 | 108.46009 | 0.82 |
| 29 1/ | 4.09337 | 91.26912 | 0.72 |
| 33 2/ | 4.13016 | 78.33914 | 0.61 |

1/ Model and parameters highly significant ($p \leq 0.01$).

2/ Intercept highly significant ($p \leq 0.01$), model and slope parameter significant ($p \leq 0.05$).

## YIELD PREDICTION BIAS

The DH values in Table 2 were used to estimate SI (base age 25) for each spacing-age combination using the equation discussed in Golden et al. (1981) (Table 4). Since total volume per acre is a function of age, SI, and a measure of stand density, yield models will predict well for any given age, SI, and density combination. However, growth and yield estimation assumes a constant SI over time. The pine density effects on SI estimation in Table 4 indicate that yield estimation based on a constant SI will result in biased estimates.

We evaluated the degree of bias in yield estimates based on our data using the North Carolina State University loblolly pine growth and yield simulator (Smith and Hafley 1986). Yields were estimated using the observed site indices in Table 4 and the observed age and density for each spacing-age combination. These yields reflect the effects of density on DH. A second set of yields was estimated from the same age and density parameters as above but using a constant SI. The constant SI selected was 69 feet, which was the average DH over all spacings at age 25.

The results of subtracting yields (actual) using observed site indices from yields (predicted) using the constant SI are shown in Table 5. The differences ranged from under-estimation of 468 $ft^3$ per acre for the 10x10 spacing at age 25 to over-estimation of 528 $ft^3$ per acre for the 6x6 spacing at age 33. As a percent of actual yields, the biases ranged from -10.1 to 16.4 percent (Table 6). The amount of bias is directly proportional to the differences between SI estimates that reflect a density relationship and the constant SI.

Table 4.--Site index estimates by spacing and age. 1/ 2/

| | Planting spacing (ft x ft) | | | | |
|---|---|---|---|---|---|
| Age | 4x4 | 6x6 | 6x8 | 8x8 | 10x10 |
| | -------Site index base age 25 (ft)------- | | | | |
| 13 | 64.4 | 67.5 | 67.4 | 69.5 | 72.0 |
| 18 | 62.2 | 64.6 | 64.8 | 65.2 | 73.4 |
| 21 | 62.6 | 67.4 | 67.2 | 67.9 | 74.9 |
| 22 | 61.8 | 66.4 | 66.6 | 66.7 | 75.6 |
| 25 | 63.5 | 69.0 | 68.7 | 67.4 | 76.8 |
| 28 | 60.4 | 66.3 | 66.8 | 65.5 | 74.2 |
| 29 | 62.0 | 67.3 | 67.3 | 65.4 | 75.0 |
| 33 | 59.4 | 66.1 | 67.4 | 64.4 | 73.5 |

1/ Site index estimates from equation developed by Golden et al. (1981).

2/ Values shown are averages of two blocks except for the 10x10 spacing, which had one replication.

Table 5.--Total cubic foot volume (i.b.) yield estimation biases from ignoring the dominant height-pine density relationship. 1/

| | Planting spacing (ft x ft) | | | | |
|---|---|---|---|---|---|
| Age | 4x4 | 6x6 | 6x8 | 8x8 | 10x10 |
| | -------Cubic foot volume per acre-------- | | | | |
| 13 | 111 | 47 | 43 | -23 | -63 |
| 18 | 206 | 164 | 159 | 167 | -161 |
| 21 | 186 | 91 | 94 | 49 | -295 |
| 22 | 223 | 141 | 93 | 103 | -353 |
| 25 | 176 | 0 | 0 | 121 | -468 |
| 28 | 369 | 181 | 121 | 209 | -333 |
| 29 | 295 | 130 | 27 | 289 | -394 |
| 33 | 489 | 528 | 129 | 354 | -344 |

1/ Yields predicted using North Carolina State Univ. loblolly pine growth and yield simulator as discussed in Smith and Hafley (1986).

Table 6.--Percentage by which yields were under- or over-estimated when the height-pine density relationship was ignored.

| | Planting spacing (ft x ft) | | | | |
|---|---|---|---|---|---|
| Age | 4x4 | 6x6 | 6x8 | 8x8 | 10x10 |
| | Percent | | | | |
| 13 | 5.8 | 2.5 | 2.6 | 1.2 | -3.6 |
| 18 | 7.2 | 5.3 | 5.5 | 5.6 | -5.1 |
| 21 | 6.1 | 2.6 | 2.8 | 1.4 | -7.6 |
| 22 | 7.5 | 3.9 | 2.8 | 2.8 | -8.8 |
| 25 | 5.7 | 0 | 0 | 2.9 | -10.1 |
| 28 | 11.8 | 4.2 | 2.9 | 4.4 | -6.7 |
| 29 | 9.0 | 2.8 | 0.6 | 6.0 | -8.0 |
| 33 | 16.4 | 15.0 | 3.0 | 8.0 | -6.9 |

## DOMINANT HEIGHT AND INTER-SPECIFIC COMPETITION

Three vegetative management studies were used to evaluate early effects of inter-specific competition on DH. The first, located on the Hill Farm Research Station in Homer, LA, had three blocks and five treatments. The treatments were: no vegetation control, one year of Velpar®, two years of Velpar®, one year of Oust®, and two years of Oust®. The study was established in 1981 with a planting spacing of 8x8 feet (681 trees per acre). The second and third studies were located at Aycock and Winnfield, LA. Four replications of four treatments were established in 1984 at a planting spacing of 8x8 feet. The treatments were: no vegetation control, herbaceous control only, hardwood control only, and total vegetation control.

### Homer Vegetation Management Study

The average height of the tallest 100 trees per acre by treatment for four growing seasons are depicted in Table 7. Averages in 1981 were from initial heights. $R^2$ values of analysis of variance (ANOV) ranged from 0.74 to 0.90, which were significant. Overall treatment effects were not significantly different. However, LSD mean comparisons detected significant differences in DH response between no vegetation control and the other treatments for all growing seasons except 1984. Oust treatments generally had a greater effect on DH than Velpar treatments. This may indicate that herbaceous weed control promotes DH growth better than hardwood control, at least at an early age.

### Aycock and Winnfield Competition Impact Studies

Tables 8 and 9 depict DH after one and two growing seasons for the Aycock and Winnfield studies, respectively. For both locations, ANOV model and treatment sums of squares were highly significant in all growing seasons.

After one growing season at Aycock, LSD mean comparisons detected no significant difference between DH response to no vegetation control and herbaceous vegetation control only. DH in hardwood control treatments was significantly higher than in the above two treatments, while total vegetation control resulted in a significantly higher DH than all other treatments.

After one growing season at Winnfield, LSD mean comparisons gave the same results as at Aycock. After two growing seasons, DH response from herbaceous only and hardwood only treatments had reversed. Herbaceous control exhibited a significantly larger DH than did hardwood control. This supports the results of the Homer location. Thus, the response of DH to different levels of inter-specific competition was significant at an early age.

Table 7.--Mean height of the tallest 100 trees per acre by year and treatment for the Homer Vegetation Management Study. 1/

| | Treatment 2/ | | | | |
|---|---|---|---|---|---|
| Year | No control | Velpar 1 year | Velpar 2 years | Oust 1 year | Oust 2 years |
| | Height (ft) | | | | |
| 1981 3/ | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 |
| 1982 | 1.4a | 1.6b | 1.7b | 1.8b | 1.7b |
| 1983 | 3.2a | 3.5b | 3.9b | 4.0b | 3.9b |
| 1984 | 5.7a | 6.0b | 6.7b | 7.0b | 6.7b |
| 1985 | 8.7a | 9.2b | 10.1b | 10.2b | 10.1b |

1/ Values shown are averages of four blocks.

2/ Means with the same letter are not significantly different ($p \leq 0.05$).

3/ From initial planting heights.

Table 8.--Mean height of the tallest 100 trees per acre by year and treatment for the Aycock Competition Impact Study. 1/

| Year | Treatment 2/ | | | |
|---|---|---|---|---|
| | No control | Herbaceous control | Hardwood control | Total control |
| | --------------Height (ft)--------------- | | | |
| 1984 3/ | 0.8 | 0.7 | 0.7 | 0.7 |
| 1985 | 1.2a | 1.3a | 1.6b | 2.0c |

1/ Values shown are averages of four blocks.

2/ Means with the same letter are not significantly different ($p \leq 0.05$).

3/ From initial planting heights.

Table 9.--Mean height of the tallest 100 trees per acre by year and treatment for the Winnfield Competition Impact Study. 1/

| Year | Treatment 2/ | | | |
|---|---|---|---|---|
| | No control | Herbaceous control | Hardwood control | Total control |
| | --------------Height (ft)--------------- | | | |
| 1984 3/ | 0.8 | 0.7 | 0.7 | 0.7 |
| 1985 | 1.2a | 1.3a | 1.6b | 2.0c |
| 1986 | 3.7a | 5.1b | 3.8a | 5.5c |

1/ Values shown are averages of four blocks.

2/ Means with the same letter are not significantly different ($p \leq 0.05$).

3/ From initial planting heights.

## CONCLUSIONS

Data from four studies showed that intra- and inter-specific competition significantly reduced DH. The inverse relationship between pine density and DH in loblolly pine was similar to that reported for slash pine by Lloyd and Jones (1982). The DH-pine density relationship is long term. Failure to recognize this relationship in growth and yield prediction can seriously bias yield estimations.

Our data showed a significant inverse relationship between inter-specific competition and DH at an early age, but long term speculation about these effects would be premature. However, this early evidence does encourage continued research into the long term effects of inter-specific competition on DH.

Despite the problems we have discussed, DH remains our best measure of site quality and is the parameter least affected by silvicultural practices. The latter fact makes DH superior to total volume as a measure of site productivity. Continued research is needed to define a site index measure that reflects the interaction between dominant height and intra- and inter-specific competition. Until such an index is defined, foresters should remain cognizant of the fact that growth and yield estimations are not as precise as modeling techniques might lead one to believe.

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# A REGION-WIDE STUDY OF LOBLOLLY PINE SEEDLING GROWTH RELATIVE TO FOUR COMPETITION LEVELS AFTER TWO GROWING SEASONS[1/]

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and

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Abstract.--A common study design was simultaneously established at 13 locations in the Southern United States to examine the scope of regional variation in loblolly pine (Pinus taeda L.) growth relative to four competition levels. The following competition levels were created and maintained for 2 years using selective herbicides and directed applications of nonselective herbicides: (a) complete control of all competition; (b) woody control, leaving the herbaceous competition; (c) herbaceous control, leaving the woody competition; and (d) no control, with both herbaceous and woody competition. Effects on planted pines are being examined at 12 locations, and natural regeneration is being studied at one Arkansas location.

During the first 2 years the herbaceous component generally had more negative influence on pine growth than the woody component. Diameter growth was more often influenced than height growth. The size of trees grown without competition represents unique benchmarks of growth across the region by which results from other vegetation management studies can be gauged.

## INTRODUCTION

Early in the life of pine plantations, an array of woody and nonwoody vegetation competes at various levels across the landscape with individual crop seedlings. If all nonarboresent vegetation is considered as herbaceous, then the array of woody and herbaceous vegetation and the resulting pine growth can be conceptually viewed as a response surface (fig. 1). Woody and herbaceous competition are the X and Y variables and pine size is the response variable, Z. Vegetation management treatments are applied to shift the amounts of these components to areas on the response surface where more favorable pine growth will occur. Unfortunately, very few areas on this response surface have been investigated, and only on a few sites, often using different types and timings of treatments. Knowing some key responses across many sites on this surface should allow scattered research findings to be compared to these knowns and thus to each other.

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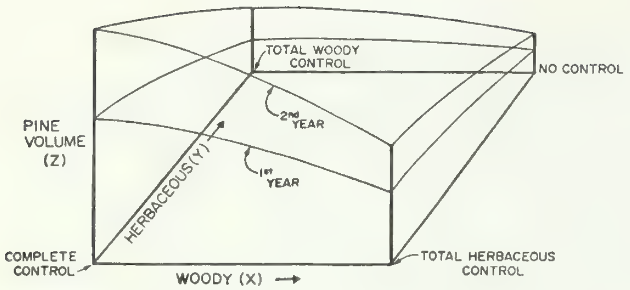


Figure 1.--Conceptual response surface showing the four corners studied in the Competition Omission Monitoring Project

In 1982, at the Second Southern Silvicultural Research Conference, a group of investigators met and began planning a project to define the four corners of this response surface. The primary study objective was to establish a southern region framework of growth response on major soil sites for newly established loblolly pine relative to four competition levels: (1) no control, (2) hardwood and shrub (woody) control, (3) herbaceous control, and (4) total competition control. These control levels are to be maintained for at least 4 years. A second objective was to make a strict comparison between the relative importance of herbaceous vs. woody competition as they affect loblolly pine growth on a wide range of sites. Measurements of plant moisture stress were to be made on two locations to aid in data interpretation. A third objective was to describe both the herbaceous and woody vegetation at each location to identify the principle competitors in the region.

This cooperative effort has since been termed the Competition Omission Monitoring Project or COMP, because selected components are omitted and pine response is closely monitored. Sixteen sites have been established using a common study plan, with some minor alterations. The 2-year results from 13 locations established in 1984 are presented in this paper.

## METHODS

### Study Locations

Study locations are shown in figure 2 and physiographic provinces noted in table 1. Locations were clearcut in late 1982 or 1983, except for Crossett, AR, and Pembroke, GA. At Crossett, hardwoods greater than 1 inch in d.b.h. were injected with herbicide in 1980 prior to a seed-tree regeneration cut (1981); then brush cutting to a height of 2.5 feet occurred before seed tree removal (1983). At Pembroke, a 6-year old plantation that had burned in a wildfire was rebedded in 1983, the only bedded study location.

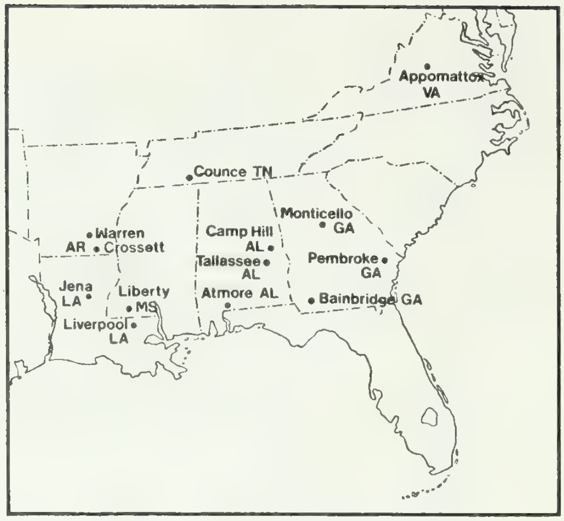


Figure 2.--Study area locations

The other sites were chopped and burned in 1983, except for Atmore, AL, which was fuelwood harvested and Counce, TN, which was sheared and windrowed. At some locations, chain saws and tree injection were used to remove scattered standing trees after site preparation.

### Plot Establishment and Treatment

Sixteen treatment plots measuring 104 by 104 ft (0.25 acres) were established at most locations using a randomized complete block design with four blocks of four plots. At Bainbridge, GA, a completely randomized design was used, and at Pembroke, GA, 20 plots were established with 5 blocks of 4 plots. All blocking was by topography except at Crossett, AR, and all slope positions were included except the medium to steep slopes. Blocking at Crossett was by pine stocking levels.

Interior measurement plots were 63 by 63 ft (0.09 acres), which accommodated precisely positioned planting spots measured at 9 by 9 ft, except at the natural regeneration and bedded sites. Thus there were 121 planting spots within the 0.25-acre treatment plots and 49 spots within the measurement plots. At each planting spot, two 1-0 loblolly pine seedlings were planted within 5 inches of the spot marker. Double planting was performed to assure full stocking for long-term growth measurements. Either improved or Livingston Parish seedlings were planted. After the first growing season, randomly generated codes were used to thin seedlings to one per spot. This was done to maintain population means and variances of initial seedling size. All 49 measurement seedlings were permanently identified. For the natural regeneration study location at Crossett, AR, 50 seedlings on each plot were randomly selected and tagged for measurements.

Table 1.--Location, physiographic province, soil series, and soil properties for two depths for each study site

| Location | Province | Soil Series | Depth | Sand | Silt | Clay | OM | Available $PO_4$ | pH |
|---|---|---|---|---|---|---|---|---|---|
| | | | inches | ----------- | percent | -------- | | mg/kg | |
| Crossett, AR | HCP[1] | Bude, Providence | 0-6 | 35 | 51 | 14 | 2.5 | 0.13 | 5.4 |
| | | | 6-24 | 33 | 51 | 16 | 0.7 | 0.03 | 5.1 |
| Warren, AR | HCP | Saffell, Stough | 0-6 | 59 | 30 | 11 | 3.7 | 2.23 | 5.7 |
| | | | 6-24 | 57 | 28 | 15 | 1.9 | 0.90 | 5.1 |
| Jena, LA | MCP | Cameran, Anacoco | 0-6 | 55 | 34 | 11 | 2.7 | 0.36 | 5.3 |
| | | | 6-24 | 46 | 30 | 24 | 1.1 | 0.03 | 5.2 |
| Liverpool, LA | MCP | Tangi, Providence | 0-6 | 39 | 49 | 12 | 3.0 | 0.25 | 5.2 |
| | | | 6-24 | 35 | 46 | 19 | 2.2 | 0.13 | 5.2 |
| Liberty, MS | MCP | Saffell | 0-6 | 75 | 20 | 5 | 2.0 | 1.35 | 5.8 |
| | | | 6-24 | 65 | 23 | 12 | 0.5 | 0.33 | 5.5 |
| Counce, TN | HCP | Silerton, Lutts | 0-6 | 9 | 54 | 37 | 2.2 | 0.10 | 4.9 |
| | | | 6-24 | 8 | 51 | 41 | 1.1 | 0.05 | 4.9 |
| Atmore, AL | MCP | Orangeburg | 0-6 | 64 | 14 | 22 | 1.5 | 0.07 | 5.4 |
| | | | 6-24 | 61 | 14 | 25 | 1.2 | 0.01 | 5.4 |
| Tallassee, AL | HCP | Cowarts | 0-6 | 83 | 11 | 6 | 1.3 | 1.79 | 5.2 |
| | | | 6-24 | 75 | 13 | 12 | 0.7 | 0.61 | 5.3 |
| Camp Hill, AL | P | Cecil, Pacolet | 0-6 | 72 | 17 | 11 | 2.1 | 0.43 | 5.4 |
| | | | 6-24 | 61 | 16 | 23 | 0.8 | 0.05 | 5.3 |
| Bainbridge, GA | MCP | Orangeburg, Esto | 0-6 | 86 | 5 | 9 | 0.9 | 0.90 | 5.8 |
| | | | 6-24 | 79 | 4 | 17 | 0.9 | 0.20 | 5.4 |
| Monticello, GA | P | Davidson | 0-6 | 64 | 20 | 16 | 3.6 | 1.05 | 5.8 |
| | | | 6-24 | 49 | 21 | 30 | 1.1 | 0.08 | 5.4 |
| Pembroke, GA | LCP | Mascottee, Pelham | 0-6 | 88 | 6 | 6 | 3.1 | 0.38 | 4.3 |
| | | | 6-24 | 88 | 7 | 5 | 1.9 | 0.33 | 4.5 |
| Appomattox, VA | P | Cecil, Cullen, Iredell | 0-6 | 42 | 34 | 24 | 3.8 | 0.85 | 4.9 |
| | | | 6-24 | 32 | 26 | 42 | 1.5 | 0.16 | 4.7 |

[1]HCP=Hilly Coastal Plain, MCP=Middle Coastal Plain; LCP=Lower Coastal Plain; P=Piedmont

The four treatments, or desired competition situations, were established and maintained as follows:

No control (none)--After the initial site preparation treatment, no further broadcast treatments were applied. Vine infestations were spot treated at most locations using shielded directed sprays of glyphosate (Roundup™) or wick applications and directed sprays of triclopyr (Garlon™).

Woody control--Preestablishment herbicide applications of foliar and basal sprays were used. For two growing seasons, three to six herbicide treatments were applied to eliminate individual hardwood stems and vine infestations using directed sprays of glyphosate and/or tricloypr and basal wipes of triclopyr. Foliar-active herbicides were used to minimize seedling damage.

Herbaceous control (herb control)--March to May applications of sulfometuron methyl (Oust™) at 3 to 6 oz product per acre were the main control treatments. In the second year, glyphosate at 18 oz product per acre or oxyfluorfen (Goal™) at 0.6 gal product per acre were included in a tank mix with sulfometuron methyl. At three to five times during a growing season, shielded directed sprays of glyphosate (2-percent solution) were applied to scattered regrowth. At Crossett and Bainbridge, sethoxydim (Poast™) was used as a broadcast spray for grass control.

Total control--A combination of treatments used on the woody and herbaceous control plots were applied as outlined above.

Through careful applications, minimum pine damage occurred within the plots.

### Measurements and Analyses

Study sites were located on prevalent series for the provinces and some locations are on common series (table 1). Soils were sampled in early spring of 1984 on all plots to characterize sites. Twenty tube (1-inch diameter) samples per plot were composited by depth; 0 to 6, 6 to 12, and 12 to 24 inches. A range of textural classes are encompassed by the study sites with most surface soils being in the loamy classes with medium to high sand contents. The exception is Counce, TN, which is a silty clay loam. Surface soil organic matter (OM) ranges from 0.9 to 3.8 percent, available phosphorus from an extremely low level at 0.07 mg/kg to a high of 2.23 mg/kg, and pH from 4.3 to 5.8.

Seedlings were measured during the winter after the first two growing seasons. Heights and groundline diameters (GLD's) were measured the first year, and diameter at 6 inches above groundline (D6) was included the second year. Damage incidence by tipmoth (Rhyacionia spp.) and fusiform rust (Cronartium quercuum (Berk.) Miyabe ex Shirai f.sp. fusiforme) were recorded by stem location for all seedlings.

Competition levels were assessed in September for the first two growing seasons to document the variation in competitive species across the region and the degree of treatment success. Woody rootstocks were counted by species and by 1-ft height categories on three systematically located 9- by 18-ft plots per measurement plot. These 9- by 18-ft plots were halved and herbaceous components (grasses, forbs, semiwoody vines, and shrubs) and bare ground were visually estimated by percent cover on the six 9- by 9-ft plots. Herbaceous species having a cover greater than 15 percent were recorded. In the second growing season, additional cover estimates were made for woody competition and crop pines. At Pembroke, GA, 11- by 15-ft plots centered on the 11-ft spaced beds were used instead of the 9- by 18-ft plots. At Crossett, AR, rootstock counts and cover estimates were made on 10 circular milacre plots per measurement plot.

Pine growth data, tipmoth and fusiform incidence, and competition cover estimates were analyzed separately by location using the appropriate analysis of variance (ANOVA) with arcsine square-root transformations for percent data. If treatments were significantly different at the 0.05 level, treatment means were separated using Duncan's multiple range test.

### Pine Moisture Stress

To delve closer into cause-and-effect relations between competition and its influence on moisture stress of pine seedlings, in late-September 1984, predawn moisture stress was taken on the pines at Tallassee and Camp Hill, AL. These locations were planted with seedling from the same source, on sites located within 30 miles of each other, representing Coastal Plain (Tallassee) and Piedmont (Camp Hill) soils. The pressure chamber method (Waring and Cleary 1967) was used on two consecutive mornings after a rainless period of about 20 days. Seedling lateral branches were clipped and xylem pressure potential (XXP) was read in negative megapascals (MPa). Eight seedlings were randomly selected from each of the four treatments on two blocks at each location. Plot means were then calculated. After inspection for homogenity, the data from both locations were combined and analyzed using ANOVA and Duncan's multiple range test. Linear regression techniques were used to explore the relation between xylem pressure potential and first-year GLD.

## RESULTS

### Woody and Herbaceous Species Composition

Panicum grasses were common at nine locations in the first year with broomsedge being the second most common grass across the region (table 2). These grasses generally increased in frequency and percentage of cover in the second year. The asteraceae forbs (asters, horseweed, dogfennel, goldenrod, etc.) played a conspicious role in early succession, with member species present but differing by location and by year. Blackberry was a component at most locations on the no control and herb control treatments. Like blackberry, honeysuckle and other vines increased coverage in the second year.

Sumacs were the most common woody species. The range of wood species and percent composition was fairly unique by location. The study locations represent a wide spectrum in the abundance of woody competition, and densities were greater than 3,000 rootstocks per acre at most locations in the second growing season.

### Cover Estimates

The success of control treatments can be judged by the cover estimates for the first and second growing seasons shown in table 4. Coverage the second year may total to more than 100 percent of the area because the herbaceous, woody, and pine covers can simultaneously occupy different aerial strata. The specified competition levels have been reached at most locations, with yearly improvements being made toward the absolute competition levels. In general, the percent bare ground in table 4 shows good overall control on total control treatments, considering the amount of competition controlled and the effort expended. Early season control of herbaceous vegetation in the first year was nearly complete at most locations following the pre-emergent herbicide applications. The late-season cover values in table 4 do not reflect this degree of control due to some subsequent regrowth of grasses and vines.

Table 2.—The percent frequency and cover of prevalent herbaceous species on no control plots in the first and second year and the percent composition of prevalent woody species in the second year (scientific names are given in Table 3)

| First Year Herbaceous | | | Second Year Herbaceous | | | Second Year Woody | | |
|---|---|---|---|---|---|---|---|---|
| Species | Frequency | Cover | Species | Frequency | Cover | Species | Composition | Rootstocks |
| | percent | percent | | percent | percent | | Percent | No./A |
| Crossett, AR | | | | | | | | |
| blackberry | 80 | 29 | blackberry | 75 | 24 | Am. beautyberry | 35 | 14,700 |
| panicum grass | 65 | 21 | honeysuckle | 60 | 26 | winged sumac | 21 | |
| honeysuckle | 55 | 21 | greenbriar | 50 | 11 | huckleberry | 19 | |
| common grape | 42 | 11 | uniola grass | 38 | 12 | sassafras | 10 | |
| Warren, AR | | | | | | | | |
| falsedandelion | 92 | 21 | panicum grass | 88 | 36 | winged sumac | 47 | 1,725 |
| panicum grass | 58 | 7 | broomsedge | 83 | 13 | bitternut hickory | 10 | |
| crotonopsis | 42 | 4 | dogfennel | 38 | 2 | white oak | 8 | |
| broomsedge | 37 | 3 | horseweed | 29 | 19 | willow | 6 | |
| Jena, LA | | | | | | | | |
| panicum grass | 87 | 20 | panicum grass | 92 | 39 | loblolly pine | 69 | 7,305 |
| dogfennel | 79 | 32 | dogfennel | 88 | 31 | winged sumac | 7 | |
| woolly croton | 42 | 10 | blackberry | 50 | 12 | southern red oak | 5 | |
| blackberry | 33 | 3 | common lespedeza | 25 | 11 | beauty berry | 5 | |
| Liverpool, LA | | | | | | | | |
| broomsedge | 83 | 29 | panicum grass | 100 | 20 | waxmyrtle | 19 | 5,243 |
| panicum grass | 79 | 15 | broomsedge | 92 | 28 | huckleberry | 16 | |
| aster | 42 | 4 | goldenrod | 54 | 5 | winged sumac | 14 | |
| goldenrod | 42 | 3 | rushes | 46 | 5 | blackgum | 10 | |
| Liberty, MS | | | | | | | | |
| | | | blackberry | 71 | 11 | winged sumac | 49 | 7,843 |
| | no | | partridge pea | 54 | 12 | dogwood | 13 | |
| | data | | goldenrod | 46 | 6 | water oak | 9 | |
| | | | honeysuckle | 46 | 8 | sweetgum | 7 | |
| Counce, TN | | | | | | | | |
| panicum grass | 100 | 35 | panicum grass | 100 | 57 | winged sumac | 47 | 2,823 |
| broomsedge | 67 | 8 | broomsedge | 100 | 32 | blackgum | 17 | |
| falsedandelion | 46 | 4 | boneset | 46 | 5 | post oak | 16 | |
| nutsedge | 21 | 2 | nutsedge | 25 | 5 | bitternut hickory | 3 | |
| Atmore, AL | | | | | | | | |
| panicum grass | 100 | 47 | panicum grass | 100 | 65 | gallberry | 83 | 10,868 |
| southern dewberry | 71 | 12 | blackberry | 58 | 7 | dogwood | 3 | |
| blackberry | 50 | 5 | broomsedge | 42 | 4 | staghorn sumac | 3 | |
| broomsedge | 37 | 3 | southern dewberry | 29 | 2 | persimmon | 2 | |
| Tallassee, AL | | | | | | | | |
| dogfennel | 63 | 1 | broomsedge | 63 | 11 | sweetgum | 51 | 3,944 |
| common lespedeza | 42 | 10 | panicum grass | 58 | 9 | water oak | 21 | |
| pineweed | 33 | 5 | dogfennel | 58 | 8 | waxmyrtle | 8 | |
| horseweed | 29 | 5 | horseweed | 33 | 7 | huckleberry | 3 | |
| Camp Hill, AL | | | | | | | | |
| panicum grass | 100 | 60 | panicum grass | 96 | 48 | winged sumac | 42 | 15,170 |
| partridge pea | 50 | 10 | aster | 50 | 11 | smooth sumac | 23 | |
| goldenweed | 42 | 8 | horseweed | 37 | 7 | water oak | 10 | |
| ragweed | 33 | 5 | broomsedge | 33 | 6 | sweetgum | 8 | |
| Bainbridge, GA | | | | | | | | |
| horseweed | 38 | 12 | dogfennel | 50 | 24 | sassafras | 34 | 6,229 |
| greenbriar | 33 | 5 | partridge pea | 42 | 15 | winged sumac | 28 | |
| partridge pea | 33 | 5 | blackberry | 29 | 11 | sweetgum | 6 | |
| trumpet creeper | 29 | 13 | greenbriar | 25 | 5 | water oak | 5 | |
| Monticello, GA | | | | | | | | |
| american burnweed | 79 | 13 | nutsedge | 58 | 12 | smooth sumac | 64 | 7,350 |
| dogfennel | 79 | 9 | little bluestem | 46 | 7 | sweetgum | 9 | |
| honeysuckle | 37 | 4 | goldenrod | 42 | 5 | persimmon | 7 | |
| little bluestem | 25 | 2 | boneset | 38 | 5 | water oak | 5 | |
| Pembroke, GA | | | | | | | | |
| panicum grass | 100 | 58 | panicum grass | 100 | 32 | gallberry | 64 | 10,472 |
| broomsedge | 87 | 11 | broomsedge | 97 | 29 | huckleberry | 14 | |
| boneset | 70 | 2 | boneset | 73 | 4 | sweetbay | 9 | |
| wiregrass | 13 | 3 | wiregrass | 20 | 4 | cudjoe | 7 | |
| Appomattox, VA | | | | | | | | |
| horseweed | 71 | 17 | desmodium | 42 | 4 | winged sumac | 51 | 8,201 |
| panicum grass | 33 | 10 | strawberry | 38 | 7 | yellow poplar | 9 | |
| pokeweed | 33 | 6 | blackberry | 37 | 4 | smooth sumac | 9 | |
| american burnweed | 33 | 4 | panicum grass | 33 | 4 | dogwood | 6 | |

Table 3.—Common and scientific names of species discussed in the text

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| Herbaceous Species | | Woody Species | |
| Am. burnweed | Erichtites hieracifolia L. | Am. beautyberry | Callicarpa americana L. |
| asters | Aster spp. | blackgum | Nyssa sylvatica Marsh. |
| blackberry | Rubus spp. | cudjoe | Jacquinia keyensis Mez. |
| boneset | Eupatorium spp. | dogwood | Cornus florida L. |
| broomsedge | Andropogon virginicus L. | gallberry | Ilex glabra L. |
| crabgrass, hairy | Digitaria sanguinalis L. | hickory, bitternut | Carya cordiformis Koch. |
| crotonopsis | Crotonopsis elliptica Willd. | huckleberry | Vaccinium spp. |
| desmodium | Desmodium spp. | loblolly pine | Pinus taeda L. |
| dogfennel | Eupatorium capillifolium Lam. | oak, post | Quercus stellata Wong. |
| falsedandelions | Pyrrhopappus carolinianus (Walt.) DC. | oak, southern red | Q. falcata Michx. |
| goldenrod | Solidago spp. | oak, water | Q. nigra L. |
| goldenweed | Polypremum procumbens L. | oak, white | Q. alba L. |
| grape, common | Vitis rotundifolia Michx. | persimmon | Diospyros virginiana L. |
| greenbriar | Smilax spp. | red maple | Acer rubrum L. |
| honeysuckle | Lonicera japonica Thumb. | sassafrass | Sassafras albidum Nutt. |
| horseweed | Conya candensis var. pusilla Nutt. | sumac, smooth | Rhus glabra L. |
| Hypericums | Hypericum spp. | sumac, staghorn | R. hirta L. |
| lespedeza, common | Lespedeza striata Thumb. | sumac, shining | R. copallina L. |
| little bluestem | Andropogon scoparius Michx. | sweetbay | Magnolia virginiana L. |
| nutsedge | Cyperus esculentus L. | sweetgum | Liquidambar styraciflua L. |
| panicum grass | Panicum spp. | waxmyrtle | Myrica cerifera L. |
| partridge pea | Cassia fasciculata Michx. | willow | Salix nigra Marsh |
| pineweed | Hypericum gentianoides L. | yellow poplar | Liriodendron tulipifera L. |
| pokeweed | Phytolacca americana [Tourn.] L. | | |
| ragweed | Ambrosia artemisiifolia L. | | |
| rushes | Juncus spp. | | |
| southern dewberry | Rubus trivialis Michx. | | |
| strawberry | Fragaria virginiana Duchesne | | |
| trumpet creeper | Campsis radicans L. | | |
| uniola grass | Chasmanthium sessiliforum Poir. | | |
| wiregrass | Aristida spp. | | |
| wooly croton | Croton capitatus Michx. | | |

The herbaceous component on the plots with no control ranged from 40 to 95 percent in the second year. Due to care in herbicide applications and innovative methods in treating woody stems, the herbaceous coverage increased in the second year on the woody control treatments at most locations. Herbaceous control has been successful at most locations, yielding less than 15 percent cover, except at Jena, LA, Crossett AR, and Bainbridge, GA. At the Jena location, severe infestations of woolly croton developed prior to evaluation. Vine infestations, although undergoing control treatments, still remain a problem at the Crossett and Bainbridge locations.

In the second year, woody cover was less than 11 percent on all woody and total control plots. Woody competition on the no control plots varied widely by location, from a low at Warren, AR, of less than 2 percent, to three locations with over 40 percent woody cover. American beautyberry and sumacs have required constant control pressure. At nine locations, the control of herbaceous competition appears to have released the woody cover, as noted by greater cover values on herb control compared to no control treatments.

Pine cover is still low after two growing seasons, but a significant response to treatment is evident at most locations. The greatest amount of pine cover was at Bainbridge and in the naturally regenerated stand at Crossett.

## Pine Response

Pine growth (table 5) at all locations was generally, but not consistently, least on the no control treatments and greatest with total control. In the first year, seedling heights were significantly different by treatment at 7 locations, while groundline diameters were significantly different at 11 locations. None of the locations with significant growth differences showed any additional growth with woody control compared to no control. Thus woody competition had not significantly detracted from growth. Herbaceous control did however yield significantly increased height growth at 5 locations and larger GLD's at 10 locations.

In the second year, diameters differed significantly between treatments at all locations, while height differed significantly at all but four

Table 4.—Percent cover of competition components and percent bare ground and loblolly pine cover after the first and second years, by treatment control classes, for 13 sites in the Southern United States

| Vegetation Control | Crossett AR | Warren AR | Jena LA | Liverpool LA | Liberty MS | Counce TN | Atmore AL | Tallassee AL | Camp Hill AL | Bainbridge GA | Monticello GA | Pembroke GA | Appomattox VA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRST YEAR | | | | | | | Bare ground | | | | | | |
| NONE | 1.0 c | 45.7 b | 13.8 b | 6.0 b | no | 25.0 b | 9.7 c | 11.2 c | 2.0 d | 8.0 b | 54.6 b | 16.3 c | 11.8 |
| WOODY | 7.1 b | 44.7 b | 17.8 b | 14.3 b | data | 30.9 b | 20.5 c | 7.7 c | 16.5 c | 13.1 b | 75.4 a | 23.7 c | 31.8 NS |
| HERB | 86.7 a | 98.3 a | 96.2 a | 62.9 a | | 93.8 a | 55.6 b | 83.5 b | 45.8 b | 21.6 b | 80.9 a | 62.1 b | 27.5 |
| TOTAL | 91.8 a | 98.7 a | 98.7 a | 56.7 a | | 97.0 a | 97.3 a | 96.1 a | 97.1 a | 82.0 a | 87.0 a | 86.8 a | 32.6 |
| | | | | | | | Herbaceous Cover | | | | | | |
| NONE | 89.2 a[1] | 54.3 a | 81.3 a | 93.7 a | no | 75.0 a | 71.4 a | 67.8 b | 87.7 a | 87.3 a | 44.6 a | 72.3 a | 55.7 a |
| WOODY | 92.3 a | 55.0 a | 83.0 a | 85.4 a | data | 69.0 a | 75.1 a | 91.8 a | 83.4 a | 80.5 a | 24.6 b | 75.7 a | 52.9 a |
| HERB | 13.1 b | 2.5 b | 1.8 b | 36.3 b | | 5.7 b | 23.6 b | 2.3 c | 1.9 b | 67.5 a | 19.0 b | 23.1 b | 37.5 b |
| TOTAL | 7.7 b | 1.3 b | 0.8 b | 43.3 b | | 2.1 b | 2.0 c | 3.0 c | 1.8 b | 13.7 b | 12.8 b | 11.3 b | 37.9 b |
| SECOND YEAR | | | | | | | Bare ground | | | | | | |
| NONE | 0.4 c | 1.6 b | 3.5 b | 1.8 c | 0.3 c | 2.7 b | 4.5 c | 7.8 c | 1.6 c | 1.6 c | 6.5 c | 3.0 c | 12.0 d |
| WOODY | 2.3 c | 4.1 b | 6.9 b | 2.5 c | 5.0 c | 4.9 b | 10.8 c | 2.7 c | 2.8 c | 2.1 c | 30.9 b | 4.7 c | 61.8 b |
| HERB | 37.5 b | 78.6 a | 54.2 a | 60.3 b | 42.5 b | 74.5 a | 67.7 b | 56.3 | 24.5 b | 9.8 b | 70.0 a | 64.1 b | 40.4 c |
| TOTAL | 73.0 a | 85.0 a | 48.4 a | 95.5 a | 90.1 a | 86.5 a | 97.4 a | 89.5 a | 96.9 a | 83.3 a | 85.5 a | 84.2 a | 92.8 a |
| | | | | | | | Herbaceous Cover | | | | | | |
| NONE | 95.0 a | 93.8 a | 90.0 a | 77.9 b | 55.8 b | 85.5 a | 75.2 a | 62.4 b | 88.9 a | 95.7 a | 69.6 a | 71.4 b | 40.4 a |
| WOODY | 96.9 a | 92.7 a | 87.8 a | 91.4 a | 83.0 a | 88.3 a | 84.4 a | 96.3 a | 95.8 a | 97.3 a | 61.7 a | 91.8 a | 34.9 a |
| HERB | 26.9 b | 2.2 b | 39.1 b | 14.6 c | 22.1 c | 5.0 b | 4.3 b | 2.2 c | 0.9 b | 70.8 b | 14.4 b | 10.1 c | 9.4 b |
| TOTAL | 22.7 b | 6.8 b | 49.9 b | 1.8 d | 2.6 d | 5.1 b | 1.8 b | 3.1 c | 2.1 b | 3.0 c | 6.2 b | 1.4 d | 3.0 b |
| | | | | | | | Woody Cover | | | | | | |
| NONE | 26.5 a | 1.8 ab | 4.8 ab | 16.9 a | 44.2 a | 7.4 ab | 22.7 a | 31.1 a | 46.5 b | 21.0 ab | 18.8 a | 25.1 a | 53.3 a |
| WOODY | 1.3 b | 0.7 b | 1.8 b | 1.3 b | 10.8 b | 1.6 bc | 1.3 b | 0.2 b | 1.4 c | 7.3 bc | 1.6 c | 1.1 b | 4.4 b |
| HERB | 31.3 a | 12.4 a | 9.4 a | 23.1 a | 31.7 a | 12.5 a | 25.7 a | 40.8 a | 70.3 a | 35.9 a | 8.8 b | 19.4 a | 52.9 a |
| TOTAL | 0.2 b | 0.3 b | 0.8 b | 0.3 b | 0.6 c | 0.2 c | 0.3 b | 0.0 b | 0.3 c | 0.3 c | 0.8 c | 2.3 b | 4.4 b |
| | | | | | | | Pine Cover | | | | | | |
| NONE | 3.2 bc | 2.0 | 2.7 b | 2.0 | 2.0 c | 4.9 b | 2.0 b | 2.0 a | 2.0 b | 3.3 c | 6.7 | 2.2 c | 2.0 |
| WOODY | 3.1 c | 2.0 NS | 2.3 b | 2.0 NS | 2.0 c | 5.3 b | 2.3 b | 2.0 c | 2.0 b | 2.3 c | 7.9 NS | 3.7 bc | 2.0 NS |
| HERB | 15.6 a | 10.0 | 7.0 a | 2.0 | 4.7 b | 8.2 a | 4.3 ab | 5.0 b | 2.0 b | 8.7 b | 7.7 | 5.0 b | 2.0 |
| TOTAL | 7.9 b | 10.0 | 5.7 a | 2.0 | 8.5 a | 8.4 a | 8.1 a | 9.0 a | 7.3 a | 15.4 a | 9.0 | 9.4 a | 2.0 |

[1]Means in a column followed by the same letter are not significantly different at the 0.05 level as determined by Duncan's multiple range test. NS=treatment effect not significant at the 0.05 level as determined by an analysis of variance and Duncan's multiple range test not applied.

Table 5.—Loblolly pine growth relative to control of competition components after the first and second years, at 13 sites in the Southern United States

| Vegetation Control | Crossett[1] AR | Warren AR | Jena LA | Liverpool LA | Liberty MS | Counce TN | Atmore AL | Tallassee AL | Camp Hill AL | Bainbridge GA | Monticello GA | Pembroke GA | Appomattox VA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRST YEAR | | | | | | | Height (feet) | | | | | | |
| NONE | 1.58 | 1.26 | 1.63 ab[2] | 1.23 | 1.63 b | 1.02 | 1.29 | 1.08 b | 1.14 b | 1.50 b | 1.17 | 1.64 c | 0.74 c |
| WOODY | 1.47 NS | 1.44 NS | 1.54 b | 1.29 NS | 1.82 b | 1.04 NS | 1.36 NS | 1.09 b | 1.18 b | 1.53 b | 1.21 NS | 1.84 bc | 0.80 bc |
| HERB | 1.33 | 1.34 | 1.77 a | 1.18 | 2.42 a | 1.02 | 1.14 | 1.37 a | 1.24 b | 1.96 a | 1.29 | 2.28 a | 0.86 b |
| TOTAL | 1.15 | 1.35 | 1.82 a | 1.26 | 2.41 a | .96 | 1.31 | 1.50 a | 1.43 a | 2.03 a | 1.32 | 2.06 ab | 1.00 a |
| | | | | | | | Groundline Diameter (inches) | | | | | | |
| NONE | 0.28 | 0.29 b | 0.46 b | 0.22 c | 0.38 c | 0.31 b | 0.23[3] b | 0.25 c | 0.20 c | 0.29[3] c | 0.21 | 0.33 b | 0.17 c |
| WOODY | 0.29 NS | 0.31 b | 0.45 b | 0.25 bc | 0.45 c | 0.33 b | 0.27 b | 0.27 c | 0.23 c | 0.25 c | 0.21 NS | 0.38 b | 0.18 c |
| HERB | 0.35 | 0.46 a | 0.64 a | 0.29 b | 0.78 b | 0.40 a | 0.25 b | 0.44 b | 0.30 b | 0.42 b | 0.26 | 0.60 a | 0.21 b |
| TOTAL | 0.30 | 0.46 a | 0.63 a | 0.32 a | 0.96 a | 0.38 a | 0.33 a | 0.59 a | 0.51 a | 0.55 a | 0.32 | 0.60 a | 0.26 a |
| SECOND YEAR | | | | | | | Height (feet) | | | | | | |
| NONE | 2.88 | 2.79 b | 4.02 b | 2.54 b | 3.67 b | 2.82 | 2.44 b | 2.71 c | 2.65 c | 4.05 b | 2.74 | 3.93 c | 2.27 |
| WOODY | 2.64 NS | 3.14 b | 3.54 b | 2.90 ab | 4.16 b | 2.85 NS | 2.61 b | 2.79 c | 2.63 c | 4.07 b | 3.28 NS | 4.52 b | 2.42 NS |
| HERB | 3.38 | 3.94 a | 5.20 a | 3.24 a | 6.34 a | 2.90 | 2.54 b | 4.47 b | 3.68 b | 6.03 a | 3.46 | 6.18 a | 2.76 |
| TOTAL | 2.54 | 4.12 a | 5.13 a | 3.48 a | 6.24 a | 2.84 | 3.29 a | 4.98 a | 4.76 a | 6.65 a | 3.91 | 6.21 a | 2.84 |
| | | | | | | | Groundline Diameter (inches) | | | | | | |
| NONE | 0.57 b | 0.71 b | 1.11[4] | 0.53 c | 0.75 d | 0.86 b | 0.50 b | 0.68 c | 0.57 c | 1.01[5] c | 0.62 c | 0.98 d | 0.43 c |
| WOODY | 0.56 b | 0.78 b | 1.13 | 0.66 c | 0.98 c | 0.89 b | 0.65 b | 0.83 c | 0.71 c | 0.87 c | 0.94 b | 1.18 c | 0.68 b |
| HERB | 1.01 a | 1.53 a | 2.11 | 0.93 b | 1.82 b | 1.21 a | 0.70 b | 1.34 b | 0.93 b | 1.46 b | 1.06 ab | 2.13 b | 0.58 bc |
| TOTAL | 0.97 a | 1.66 a | 2.32 | 1.23 a | 2.30 a | 1.31 a | 1.19 a | 2.10 a | 1.81 a | 2.49 a | 1.31 a | 2.41 a | 0.98 a |
| | | | | | | | Diameter at 6 Inches above Groundline (inches) | | | | | | |
| NONE | 0.44 b | 0.54 b | 0.88 b | 0.44 c | 0.63 d | 0.67 b | 0.49 b | 0.51 c | 0.45 c | 0.78 c | 0.51 c | 0.74 c | 0.32 c |
| WOODY | 0.44 b | 0.61 b | 0.79 b | 0.56 c | 0.82 c | 0.68 b | 0.62 b | 0.63 c | 0.55 c | 0.82 c | 0.78 bc | 0.90 c | 0.53 b |
| HERB | 0.76 a | 1.21 a | 1.62 a | 0.78 b | 1.53 b | 0.92 a | 0.66 b | 1.05 b | 0.73 b | 1.35 b | 0.87 ab | 1.73 b | 0.44 bc |
| TOTAL | 0.72 a | 1.34 a | 1.60 a | 1.04 a | 2.01 a | 0.99 a | 1.06 a | 1.68 a | 1.53 a | 2.09 a | 1.10 a | 1.97 a | 0.76 a |
| | | | | | | | Tipmoth Infestation - Branch and/or Stem (percent infested) | | | | | | |
| NONE | 38.2 | 77.1 b | 43.1 | 98.0 | 89.4 ab | 99.5 | 95.9 | 97.3 | 42.8 b | 99.0 | 93.1 | 0 | 16.7 b |
| WOODY | 34.8 NS | 82.6 ab | 41.0 NS | 99.0 NS | 90.4 ab | 100.0 NS | 98.4 NS | 98.9 NS | 68.2 a | 99.0 NS | 98.9 NS | 0 NS | 31.8 b |
| HERB | 39.9 | 91.7 ab | 36.7 | 99.5 | 94.6 a | 100.0 | 92.7 | 98.4 | 47.8 b | 100.0 | 97.2 | 0 | 26.4 b |
| TOTAL | 32.0 | 90.6 a | 38.4 | 99.4 | 80.8 b | 100.0 | 93.2 | 100.0 | 33.0 b | 85.7 | 96.7 | 0 | 51.7 a |
| | | | | | | | Fusiform Rust Incidence - Branch and/or Stem (percent infected) | | | | | | |
| NONE | 3.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 b | 0.0 b | 4.6 | 2.1 ab | 0.4 | 0 |
| WOODY | 4.2 NS | 0 NS | 0 NS | 0.5 NS | 0 NS | 0 NS | 0 NS | 1.1 b | 1.6 b | 2.6 NS | 0.6 b | 1.2 NS | 0 NS |
| HERB | 2.5 | 0.5 | 0.5 | 0 | 0 | 0 | 0.6 | 4.8 a | 1.5 b | 6.7 | 1.6 ab | 3.4 | 0 |
| TOTAL | 1.6 | 0 | 0.5 | 0 | 0 | 0 | 0 | 7.7 a | 6.3 a | 7.7 | 4.3 a | 1.7 | 0 |

[1] Naturally regenerated stands, all others are plantation establishments.
[2] Means in a column followed by the same letter are not significantly different at the 0.05 level as determined by Duncan's multiple range test. NS=treatment effect not significant at the 0.05 level as determined by an analysis of variance and Duncan's multiple range test not applied.
[3] Actually D6.
[4] Only one block measured.
[5] Mean of five trees per plot.

sites. Of the nine locations with significant differences in second year heights, eight of these showed no difference between the woody control situation and no control. Likewise, D6's were not different at 11 locations when comparing woody control and no control. Thus herbaceous competition has acted similar to total competition in detracting growth. The same trends with herbaceous competition, yielding reduced growth, were also evident with the second year GLD's, but results of the mean separations were more variable in groupings. The largest seedlings for both the first and second year were grown on lower and middle Coastal Plain sites.

Tipmoth infested seedlings averaged greater than 80 percent at eight locations, which resulted in few significant differences due to treatment. At Warren, AR, all control treatments showed increased tipmoth incidence, especially the herb and total control treatments. At Liberty, MS, herb control treatments also yielded the most trees attacked, but total control had the least. At Camp Hill, AL, woody control treatments had the most tipmoth incidence, while at Appomattox, VA, the total control was significantly greater than the other competition situations.

Fusiform rust infection was greatest in the area of normally high incidence--upland sites in Alabama and Georgia. Increased infection was found mainly with increasing control of the herbaceous component. Monticello, GA, had lower levels of herbaceous cover on the no control treatments (table 4), which may have influenced increased rust incidence.

The overall pine size means for the plantation sites are presented in table 6. This shows more clearly the trend of improved early growth with herbaceous weed control. Seedlings in the first year on the total control treatment were 75 percent larger in GLD's and 18 percent taller when compared to the no control treatments. Herbaceous control alone yielded seedlings that were 50 percent larger in diameter and 14 percent taller, while seedlings on the woody control treatments were only slightly larger than the no control pines. After the second growing season, the size differences were attenuated. Seedlings with total control averaged 147 percent larger in GLD's, 145 percent larger in D6's, and 47 percent taller when compared to those with maximum competition. In comparison to the no control situation, seedlings on plots where only the herbaceous competition was controlled resulted in GLD's that were 85 percent larger compared to only 26 percent larger with woody control. Many locations had seedlings that were 8 ft tall with 2-inch GLD's after two growing seasons of total control.

Table 6.--Overall diameter and height means for planted loblolly pine sites by treatment after the first and second years[1]

| Vegetation Control | First Year GLD[2] | First Year Height | Second Year GLD | Second Year D6[3] | Second Year Height |
|---|---|---|---|---|---|
| | inches | feet | inches | inches | feet |
| None | 0.28 | 1.26 | 0.66 | 0.56 | 2.96 |
| Woody | 0.30 | 1.33 | 0.83 | 0.68 | 3.18 |
| Herb | 0.42 | 1.44 | 1.22 | 1.04 | 4.05 |
| Total | 0.49 | 1.49 | 1.63 | 1.37 | 4.34 |

[1] Bainbridge, GA, not included due to missing diameter data.
[2] GLD=groundline diameters.
[3] D6=diameter at 6 inches above groundline.

Pine Moisture Stress

The averages of the moisture stress readings are presented in table 7. The relation between first-year GLD's and plant moisture stress can be seen in figure 3. GLD's were reduced in a nonlinear trend as plant moisture stress increased. The selected regression relation is: $\ln(GLD)=0.465 + 2.87\ PMS + 1.02\ PMS^2$, where GLD is in inches and PMS is in negative megapascals of xylem pressure potential ($r^2$=0.93).

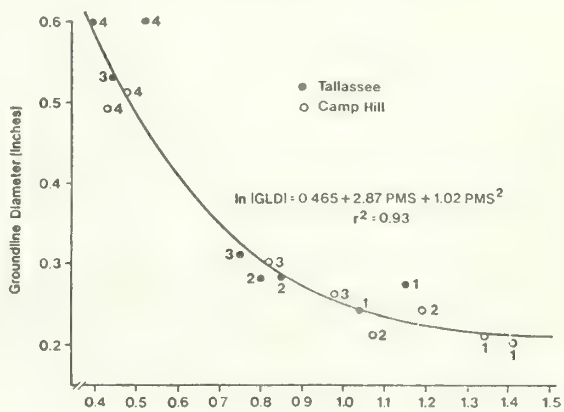


Figure 3.--The relation between xylem pressure potential taken in September and groundline diameters after the first year. 1=no control, 2=woody control, 3=herbaceous control and 4=total control

DISCUSSION

Just how competition affects pine growth is not fully known, only that competition influences the availability of the essential factors of water, nutrients, sunlight, and growing space. When pine seedlings are small, both woody and herbaceous components compete for all of these factors. After about 3 to 4 years, surviving

Table 7.--Xylem pressure potential of loblolly pines taken on September 27 and 28, 1984, during the first growing season after 20 days without rainfall

| Vegetation Control | Tallassee | Camp Hill | Overall[1] |
|---|---|---|---|
| | ---------negative MPa--------- | | |
| None | 1.10 | 1.37 | 1.23 a |
| Woody | 0.83 | 1.13 | 0.98 ab |
| Herb | 0.60 | 0.90 | 0.75 bc |
| Total | 0.46 | 0.45 | 0.46 c |

| ANOVA Results: | Pr>F |
|---|---|
| Treatment | 0.02 |
| Block | 0.71 |
| Treatment x Block | 0.24 |

[1]Overall means followed by the same letter are not significantly different at the 0.05 level as determined by Duncan's multiple range test.

pines will stand above herbaceous competitiors and only woody species influence sunlight and aerial growing space. Possibly, herbaceous weeds offer little pine competition after 7 years (Clason 1978). Hardwoods can continue to compete for all essential factors throughout the rotation since they capture both aerial and rooting space.

On most upland sites it is generally assumed that moisture is the most limiting factor when pine growth is affected by competition. Nelson and others (1981) reported that reduced moisture stress as a result of herbaceous weed control was associated with increased early loblolly pine growth. On sites where moisture was not limiting, weed control did not result in increased growth. Carter and others (1984) found that both woody and herbaceous competition influenced loblolly pine moisture stress more than they influenced foliar nutritional status. Higher moisture stress levels were found on Piedmont soils compared to pines growing on Coastal Plain soils, the same as found in the current study. In viewing the current data growth of loblolly pine seedlings, and stress levels of -1.4 MPa induced seedling dormancy (Cannell and others 1978). Thus only on the lowest competition levels was moisture stress reduced to levels where growth occurring before daylight was not negatively influenced. More information will be reported on nutritional-competition interactions since all COMP locations sampled foliage after the second growing for nutrient analysis in cooperation with the North Carolina State Forest Tree Nutrition Cooperative.

have severe hardwood competition developing. On herb control plots, some pines that are completely surrounded by taller hardwoods already appear retarded. With herb control both the pines and hardwoods have been equally released and the race for canopy position has accelerated, freed of herbaceous weed competition.

The COMP growth values represent biological standards for loblolly pine on the specific study sites and relative to patterns in precipitation. Sizes and growth increments of pine grown completely without competition approach as absolute a value as we have in vegetation management research. At the opposite end of the scale are growth values on plots with no competition control. The growth between these extremes represents a wide spectrum of possibilities for loblolly pine. These growth values may be usable as a gauging network to assess relative growth for other studies.

The values for the woody control treatments represent the ideal of most operational herbicide treatments for site preparation--control of all woody competition. The long-term value of this current strategy will be evaluated by future COMP test results. Woody control plots should also be similar to abandoned fields or pastures that have been planted or seeded with pines.

Perhaps the most interesting treatment is herbaceous control that allows site resources to be available to only woody vegetation and lets the total wood production of both pines and hardwood be realized. Hardwood growth will be measured more intensively in the coming years to determine the range of volume mixtures possible with total herbaceous control.

## CONCLUSIONS

Herbaceous competition detracts more from early growth of loblolly pines than does juvenile hardwood competition. Pine diameters were reduced by herbaceous competition more often than heights. The absence of any competition for 2 years yielded pine seedlings that were about 50 percent taller and 1.5 times larger in diameter than seedlings grown on predominantly chop and burn treated sites where there was no additional competition control. The predominate herbaceous competitors were panicum grasses, bluestems, and asteraceae forbs. Fusiform rust in high incidence areas may be significantly increased following control of herbaceous vegetation. Tipmoth incidence appears to be more a function of location than of vegetation control treatment.

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# PIEDMONT BOTTOMLAND HARDWOOD REGENERATION RESPONDS TO PREHARVEST JAPANESE HONEYSUCKLE CONTROL[1]

E.J. Schmeckpeper, R. Lea, D. Phillips, and L. Jervis.[2]

ABSTRACT.-- Preharvest herbicide treatment with Glyphosate of Japanese honeysuckle (Lonicera japonica) was followed by clearcut harvesting and chainsaw felling of residual stems. Treated plots had significantly less area covered by honeysuckle than control plots in which no herbicides were applied. Hardwood regeneration on the treated plots was primarily of seedling origin compared to predominantly sprout origin on the controls. Treated areas had significantly more free-to-grow stems of desirable species, fewer stems of undesirable species, and less honeysuckle competition than the control areas. Initial oak advanced regeneration was adversely affected by the preharvest herbicide treatment. Oak regeneration also appeared to be affected by the herbicide treatment although this was not significant.

Keywords: Clearcutting, Competition, Weeds, Herbicides.

## INTRODUCTION

There are more than 28 million acres of land classified as commercial forest land in the Piedmont of which approximately 17 million acres are in hardwood forest types. Within the hardwood type over 1.9 million acres are classified as Piedmont bottomland hardwood forests (Bechtold and Phillips 1983).

Most of the valuable hardwood species found on bottomland site types are intolerant to moderately tolerant of shade (Putnam et al. 1960), and are best managed with an even-aged system. Clearcutting with residual control of culls, low quality trees, and undesirable species is recommended for regenerating these sites (Bowling and Kellison 1983; Kellison et al. 1981; Loftis 1980; McGee 1982; McGee and Hooper 1970; Zobel and Davey 1975). However, clearcutting has not been completely successful on Piedmont bottomlands, primarily because of competition from woody and herbaceous vines (Kellison 1977; Bruner 1967).

The weed species of primary concern in Piedmont bottomlands is Japanese honeysuckle (Lonicera japonica), a climbing, semi-evergreen woody liana.

Although Japanese honeysuckle is deciduous in the Northeast, it is an evergreen plant in the Piedmont. It produces large quantities of seed which are disseminated by birds and animals (Leatherman 1955), and dispersed by floodwaters (Brender 1960). Once established, honeysuckle spreads by layering and can rapidly dominate openings in the forest canopy. Honeysuckle is present throughout the Piedmont and grows well on many soil types (Craver 1982; Leatherman 1955).

Honeysuckle stem elongation begins before deciduous tree seedlings undergo budbreak. While kept in check by a closed canopy, honeysuckle takes advantage of openings and rapidly forms dense mats. These mats may smother shrubs, tree seedlings and saplings, and may inhibit the establishment of a new crop of trees (Brender 1961).

Studies with Japanese honeysuckle indicate that it grows relatively poorly in terms of biomass at very low light intensities (i.e., 5 to 10% of full sunlight) (Leatherman 1955; Blair 1982). However, maximum shoot growth occurs at 10 to 25% of full sunlight (Leatherman 1955; Schmeckpeper 1986). Thus, crown openings large enough to permit adequate hardwood regeneration are also large enough to allow significant honeysuckle growth and subsequent intense competition.

Clearcutting in combination with a preharvest herbicide treatment has demonstrated potential for reducing competition from undesirable species on Piedmont bottomland sites. This study evaluates the effects of preharvest herbicide treatments with Glyphosate[3], in combination with clearcutting, on Japanese honeysuckle competition and natural hardwood regeneration.

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[3] The use of tradenames is for the convenience of the reader and does not constitute an official endorsement or censure.

## PROCEDURES

### Study Area

This study was located on the North Carolina State University Hill Demonstration Forest in Durham County, North Carolina. It occurs in a natural hardwood site on a narrow floodplain along Dial Creek. This site was chosen to test the effects of a preharvest application of the herbicide Glyphosate on competing understory vegetation consisting primarily of Japanese honeysuckle.

The six acre study area was divided into three blocks approximately 2-acres in size. Each block was divided in half, perpendicular to Dial Creek, One half of each block received the herbicide treatment, and the other half maintained as a control.

### Treatments

In the treated portions of each block, a foliar spray of 1.5% Glyphosate solution was applied with a backpack sprayer to all understory vegetation at a rate of 12 gal/ac during mid-July 1982. In August 1983, areas with Japanese honeysuckle that were missed by the first application received a follow-up spraying with a similar solution to that used in 1982. Prior to the follow-up spraying, the advanced reproduction, stems shorter than 4.5 ft, was inventoried in the entire study area and percent ground cover of Japanese honeysuckle was estimated ocularly.

The 6-acre stand was harvested in the winter of 1983-1984 using chainsaws. Residuals greater than 2 inches DBH were chainsaw-felled following the harvest. Regeneration and competing vegetation were inventoried at the end of the two growing seasons following the harvest.

### Data Collection

The regeneration inventory included the inventory of the following parameters:

1) tree species.
2) stem origin (seedling or sprout).
3) presence and type of competing vegetation (e.g. honeysuckle, other liana species, grasses, sedges, etc.),
4) percent of the sample plot area covered by liana vegetation (determined ocularly and rechecked with a dotgrid),
5) height of the liana competition,
6) number of tree stems potentially suppressed by liana competition,
7) ability of the dominant stem of each sprout cluster or each seedling to grow freely,

To assess the biomass accumulation of each treatment a one-meter square plot was randomly placed near each sample plot. On these plots, all non-tree vegetation was clipped, separated into liana and non-liana classes, and oven-dried.

## RESULTS AND DISCUSSION

### Preharvest Stand Characteristics

Prior to harvest, the Dial Creek bottomland stand was composed primarily of: yellow-poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), oaks (*Quercus* spp.), sycamore (*Platanus occidentalis*), and ash (*Fraxinus* spp.). Scattered shortleaf (*Pinus echinata*) and loblolly ( *P. taeda*) pines were also present.

One year after the initial herbicide application and prior to harvest, honeysuckle control appeared to be effective. Ground cover of the noxious weed was reduced to an average of 6% from approximately 40%. However, advanced reproduction of some desirable species was adversely affected by the herbicide.

The advanced reproduction and sapling inventory conducted prior to the follow-up herbicide application indicated that an average of 1180 stems per acre of desirable species less than 4.5 feet tall were in the control plots, and only 250 desirable stems per acre were in the herbicide treated plots (Table 1). The reduction in oak and hickory (*Carya* spp.) reproduction showed these species to be especially susceptible to the herbicide. Other species present on the control plots, sweetgum, yellow-poplar, ash, and blackgum (*Nyssa* spp.), either did not occur or were killed on the treated plot. The susceptibility of oak and hickory to Glyphosate has been shown by other researchers (Moran 1984).

Table 1.- Preharvest inventory of advanced reproduction on Dial Creek (height < 4.5 feet) one growing season after preharvest competition control treatment with Glyphosate herbicide.

| Species | Treatment: Control | Treatment: Treated |
|---|---|---|
| | (stems per acre) | |
| Oaks | 367 | 84* |
| Sweetgum | 88 | 0 |
| Yellow-poplar | 13 | 0 |
| Ash | 129 | 0 |
| Hickories | 500 | 166* |
| Total Desirables | 1263 | 250* |
| Other Species[1] | 4800 | 1210* |

[1] Includes ironwood, dogwood, and non-commercial hardwood species.

* Indicates a significant difference between treatment and control at the 0.05 probability level.

### Effect of Herbicide Treatment on Competition

Two years after the Dial Creek stand was harvested, the herbicide treatment continued to exert control on honeysuckle competition. The area covered by Japanese honeysuckle and other liana competition was significantly less on treated plots than on the controls (Table 2).

Table 2.- Average percent ground cover by Japanese honeysuckle in a naturally regenerated Piedmont bottomland hardwood stand at one and two growing seasons following clearcutting.

| | Percent Ground Area Covered | |
|---|---|---|
| Year | Control | Treated |
| 1 | 41.9 | 20.4* |
| 2 | 43.2 | 24.0* |

* Indicates a significant difference between treatments at the 0.05 level.

Total biomass of all competing vegetation, both liana and nonliana, was approximately equal between treatments (Table 3). Space created by removing honeysuckle was filled by other plants, especially annuals.

Table 3.- Biomass of lianas and other competing vegetation on a naturally regenerated Piedmont bottomland hardwood stand the second growing season following clearcutting.

| | Tons per Acre | |
|---|---|---|
| Vegetation | Control | Treated |
| Honeysuckle & other lianas | 1.41 | 0.92 |
| Nonlianas | 0.54 | 0.98* |
| Total | 1.95 | 1.90 |

* Indicates a significant difference between control and treatment class at the 0.05 level.

By the end of the second growing season, honeysuckle was found in the same proportions in both the treated and control plots (Table 4). However, treated plots had more annuals, grasses, and sedges than the control plots. Although the biomass of Japanese honeysuckle was significantly affected by the herbicide treatment, it was not eradicated by this treatment. Honeysuckle was present on nearly all plots in the treated areas. The implications are that honeysuckle has the potential to reclaim large portions of the site.

Table 4.- Percent of plots with Japanese honeysuckle and other weed species present on a naturally regenerated Piedmont bottomland hardwood stand for the two growing seasons following clearcutting (No significant differences were found between treatments within years at the 0.05 probability level).

| | Presence of Vegetation | | | |
|---|---|---|---|---|
| | Control | | Treated | |
| Species Class | Year 1 | Year 2 | Year 1 | Year 2 |
| | Percent | | | |
| No Competition | 0 | 2 | 13 | 0 |
| Honeysuckle | 94 | 96 | 78 | 96 |
| Annuals* | 9 | 21 | 5 | 44 |
| Blackberry | 14 | 19 | 2 | 21 |

* Includes grasses, sedges, and other annual herbaceous vegetation.

Regeneration Measurements

Two growing seasons following the commercial harvest and residual removal, in the winter of 1983 - 1984 an average of 3540 stems/ac was found on the control plots and 5210 stems/ac on the treated plots (Table 5). Treated plots had significantly more and higher proportions of seedlings per acre than the control plots.

Table 5.- Comparison of seedling and sprout regeneration (number of stems per acre) of a naturally regenerated Piedmont bottomland hardwood stand for two growing seasons following clearcutting.

| | Treatment | | | |
|---|---|---|---|---|
| | Control | | Treated | |
| Origin | Year 1 | Year 2 | Year 1 | Year 2 |
| | (stems per acre) | | | |
| Seedlings | 4360 | 1430 | 8510* | 3860* |
| Sprouts | 3140 | 2110 | 1010* | 1350 |
| Total | 7500 | 3540 | 9520* | 5210 |

* Indicates a significant difference between treatments within years at the 0.05 probability level.

In both the first and the second growing seasons following harvest, the control plots had more tolerant undesirable species which sprouted vigorously after harvest (e.g. ironwood (Carpinus caroliniana), dogwood (Cornus florida), and sourwood (Oxydendrum arboreum)) than the herbicide treated plots (Table 6). Conversely, many sapling-sized dogwood and ironwood trees were killed by the preharvest herbicide treatment and did not resprout after the harvest. Loftis (1985) reported similar reductions in numbers of stems of undesirable species following preharvest herbicide treatments.

Table 6.- Comparison of seedling and sprout regeneration of desirable and undesirable tree species of a naturally regenerated Piedmont bottomland hardwood stand for two growing seasons following clearcutting.

| | Treatment | | | |
|---|---|---|---|---|
| | Control | | Treated | |
| Origin | Year 1 | Year 2 | Year 1 | Year 2 |
| | (stems per acre) | | | |
| Desirables | | | | |
| Seedlings | 3440 | 1250 | 7800* | 3770* |
| Sprouts | 850 | 630 | 450 | 490 |
| Undesirables | 3210 | 1660 | 1270* | 950 |

* Indicates a significant difference between treatments and within years at the 0.05 probability level.

Sprouts also made up a higher proportion of the desirable stems in control plots. At the end of the second growing season, only 11.4% of the desirable stems in the treated plots were sprouts. In contrast, sprouts composed 33.7% of the desirable stems on the control plots.

Effects of the preharvest herbicide treatment on species composition are reflected by the distribution of desirable species (Table 7). In the control plots, oaks comprised 11.2% of the desirables in year one and 8.9% in year two. However, oaks were negligible on the treated plots. Species which regenerate prolifically by seed, such as yellow-poplar were present in greater proportions on the treated plots.

Table 7.- Distribution of regeneration of desirable tree species of a naturally regenerated Piedmont bottomland hardwood stand for two growing seasons following clearcutting.

| Species | Control Year 1 | Control Year 2 | Treated Year 1 | Treated Year 2 |
|---|---|---|---|---|
| | (percent) | | | |
| Desirables: | | | | |
| Yellow-poplar | 68.0 | 59.1 | 82.0 | 82.6 |
| Sweetgum | 1.4 | 3.2 | 3.9 | 2.4 |
| Sycamore | 0.5 | 3.2 | 5.4 | 2.9 |
| Ash | 0.9 | 4.3 | 0.7 | 1.0 |
| White Oaks | 6.5 | 2.3 | 0.5 | 0.5 |
| Red Oaks | 4.7 | 6.6 | 1.0 | 0.5 |
| Hickory | 1.7 | 5.5 | 2.2 | 2.4 |
| Blackgum | 8.6 | 10.9 | 0.0 | 4.9 |
| Other Desirables[1] | 7.7 | 4.9 | 4.3 | 2.8 |

[1] Includes shortleaf and loblolly pines and other desirable hardwood species.

With less Japanese honeysuckle on the treated areas there were fewer suppressed stems. At year 2, 83% of all stems on the control plots were classified as suppressed, compared to 50% on the treated plots (Table 8). In the control, an average of less than 600 free-to-grow stems per acre of desirable species were found; in treated areas an average of 2570 free-to-grow desirables per acre was found. Although trees may grow through honeysuckle mats after several years (Hurst and Bourland 1980), the effects of the competition on stem quality and the numbers of merchantable stems at rotation's end is not known. However, even with 590 stems per acre on the control areas, it appears that the stand will be fully stocked at the end of the rotation.

Table 8.- Comparison of total free-to-grow (F.T.G.) regeneration and free-to-grow regeneration of desirable tree species on a naturally regenerated Piedmont bottomland hardwood stand for two growing seasons following clearcutting.

| Year | Total F.T.G. Control | Total F.T.G. Treated | F.T.G. Desirable Control | F.T.G. Desirable Treated |
|---|---|---|---|---|
| | (stems per acre) | | | |
| 1 | 2900 | 7850* | 2347 | 6840* |
| 2 | 1240 | 3020* | 590 | 2570* |

* Indicates a significant difference between treatments and within a vegetation class at the 0.05 probability level.

In this stand, injection of the undesirable residuals might have been a better treatment than clear-felling. Injection of residuals may reduce vine problems by reducing slash and logging debris which honeysuckle uses as a platform (Hurst and Bourland 1980).

Another alternative to this treatment for competition control is a herbicide treatment in the autumn, after overstory leaf fall. Little and Somes (1968) reported good honeysuckle control one year after an October spraying. Although some mortality of advanced hardwood regeneration was reported, the authors speculated that less hardwood damage would have occurred with the same degree of honeysuckle control if the spraying had been delayed until leaves of the overstory trees had fallen.

## SUMMARY AND RECOMMENDATIONS

Preharvest application of Glyphosate produced desirable results in Piedmont bottomland hardwood stand examined in North Carolina. Significantly greater numbers of unsuppressed stems were found in areas which received the herbicide treatment. The higher proportion of desirable stems on the treated plots could produce a more valuable stand at the end of the rotation.

Many Piedmont bottomland stands have been high-graded and, as a result, have large numbers of culls and undesirable species. Preharvest herbicide treatments may be useful in rehabilitating these sites by reducing regeneration of undesirable species.

Although the preharvest Glyphosate treatment was effective in reducing honeysuckle competition and cover, some detrimental side effects occurred. Oak advanced reproduction was adversely affected by the herbicide which could result in fewer oaks in the ensuing stand. Alternative treatments to avoid impacts on desired species include spraying after leaf fall or injecting rather than chainsaw felling residuals. Research is needed to determine if oak regeneration is permanently affected, and if such a loss outweighs the benefits of the herbicide treatments.

On sites with understories relatively free of Japanese honeysuckle, small clearcuts with residual control will most likely be sufficient for regeneration. Clearcuts smaller than 0.5 acres may not be large enough to allow sufficient sunlight for regeneration of shade intolerant desirable species. However, failure to control honeysuckle before harvesting may result in fewer free-to-grow desirable seedlings and sprouts. This research suggests that the long-term effects of Japanese honeysuckle competition on hardwood regeneration, species composition, and timber quality of the subsequent stand need further tracking in light of its significant impacts on early stand establishment.

This study covers only the first two years of a dynamic system. Changes in species composition and dominance will continue as the stand develops. Further study of long-term herbicide treatment effects on honeysuckle competition and stand development is needed to determine if honeysuckle damage is sufficient to warrant such treatments.


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